



US009436184B2

(12) **United States Patent**
D'Andrea et al.

(10) **Patent No.:** **US 9,436,184 B2**
(45) **Date of Patent:** **Sep. 6, 2016**

(54) **METHOD AND SYSTEM FOR TRANSPORTING INVENTORY ITEMS**

(71) Applicant: **Amazon Technologies, Inc.**, Reno, NV (US)

(72) Inventors: **Raffaello D'Andrea**, Wollerau (CH); **Peter K. Mansfield**, Bellevue, WA (US); **Michael Cordell Mountz**, Lexington, MA (US); **Dennis Polic**, Medford, MA (US); **Patrick R. Dingle**, Salem, MA (US)

(73) Assignee: **Amazon Technologies, Inc.**, Reno, NV (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 206 days.

(21) Appl. No.: **14/252,570**

(22) Filed: **Apr. 14, 2014**

(65) **Prior Publication Data**

US 2014/0228999 A1 Aug. 14, 2014

Related U.S. Application Data

(60) Continuation-in-part of application No. 13/553,024, filed on Jul. 19, 2012, now Pat. No. 8,725,286, which is a continuation of application No. 12/890,197, filed on Sep. 24, 2010, now Pat. No. 8,280,546, which is a division of application No. 11/423,294, filed on Jun. 9, 2006, now Pat. No. 7,826,919.

(51) **Int. Cl.**
G06F 7/00 (2006.01)
G05D 1/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **G05D 1/021** (2013.01); **B65G 1/0492** (2013.01); **B65G 1/1378** (2013.01); **B66F 9/063** (2013.01); **G05D 1/0234** (2013.01); **G06Q 10/087** (2013.01); **G05D 2201/0216** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,972,917 A 11/1990 Matsumoto et al. 180/168
5,281,901 A * 1/1994 Yardley G05D 1/0265
180/167

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0 244 984 A2 11/1987 B66F 9/18
FR 2 689 488 A1 4/1992 B65G 63/00
WO WO 2006/0441808 A2 4/2006

OTHER PUBLICATIONS

PCT Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, with attached International Search Report and the Written Opinion of the International Searching Authority in International Application No. PCT/US2007/011302, dated Nov. 7, 2008, 12 pages.

(Continued)

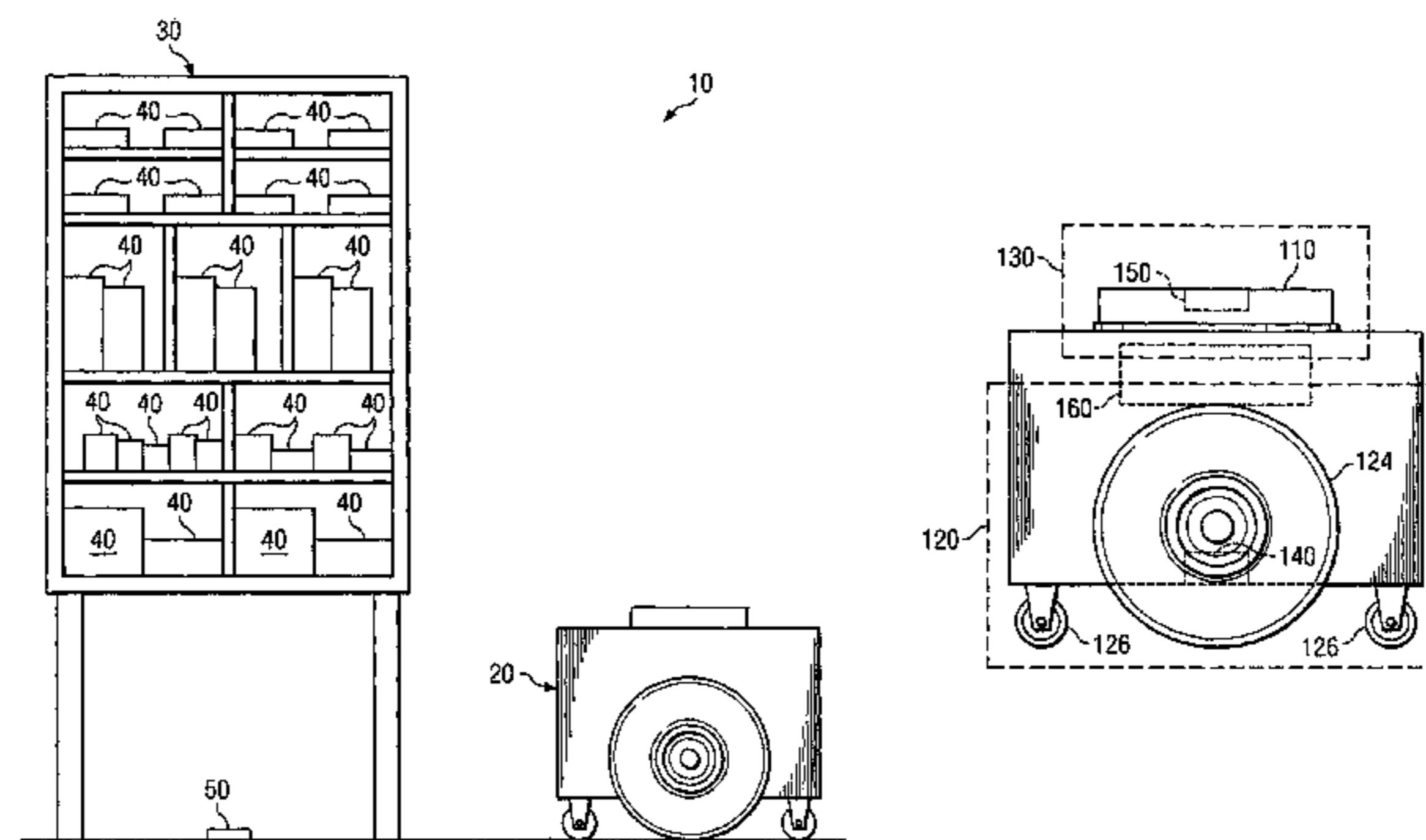
Primary Examiner — Yolanda Cumbess

(74) *Attorney, Agent, or Firm* — Baker Botts L.L.P.

(57) **ABSTRACT**

A system for transporting inventory items includes an inventory holder capable of storing inventory items and a mobile drive unit. The mobile drive unit is capable of moving to a first point with the inventory holder at least one of coupled to and supported by the mobile drive unit. The mobile drive unit is additionally capable of determining a location of the inventory holder and calculating a difference between the location of the inventory holder and the first point. The mobile drive unit is then capable of determining whether the difference is greater than a predetermined tolerance. In response to determining that the difference is greater than the predetermined tolerance, the mobile drive unit is also capable of moving to a second point based on the location of the inventory holder, docking with the inventory holder, and moving the mobile drive unit and the inventory holder to the first point.

19 Claims, 10 Drawing Sheets



US 9,436,184 B2

Page 2

(51)	Int. Cl.								
	B65G 1/137	(2006.01)		8,170,711 B2	5/2012	D'Andrea et al.	.....	700/214	
	B66F 9/06	(2006.01)		2003/0233177 A1*	12/2003	Johnson	.....	G05D 1/0236	
	B65G 1/04	(2006.01)						701/23	
	G06Q 10/08	(2012.01)		2004/0010337 A1*	1/2004	Mountz	.....	G05D 1/0274	
								700/214	
				2011/0130866 A1	6/2011	D'Andrea et al.	.....	700/214	

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,658,120 A	8/1997	Watanabe	.....	414/495
5,993,045 A	11/1999	Schmidtke et al.	.....	700/214
6,823,236 B2	11/2004	Speckhart et al.	.....	700/215
7,107,121 B2	9/2006	Fisher et al.	.....	700/229
7,151,979 B2	12/2006	Andersen et al.	.....	700/24

OTHER PUBLICATIONS

Canadian Patent Office Official Action in Canadian Patent Application No. 2,652,114, dated Nov. 5, 2009, 4 pages., Nov. 5, 2009.
Japanese Patent Office Action for Application No. 2009-514267.6; 6 pages (including translation), Dec. 7, 2011.

* cited by examiner

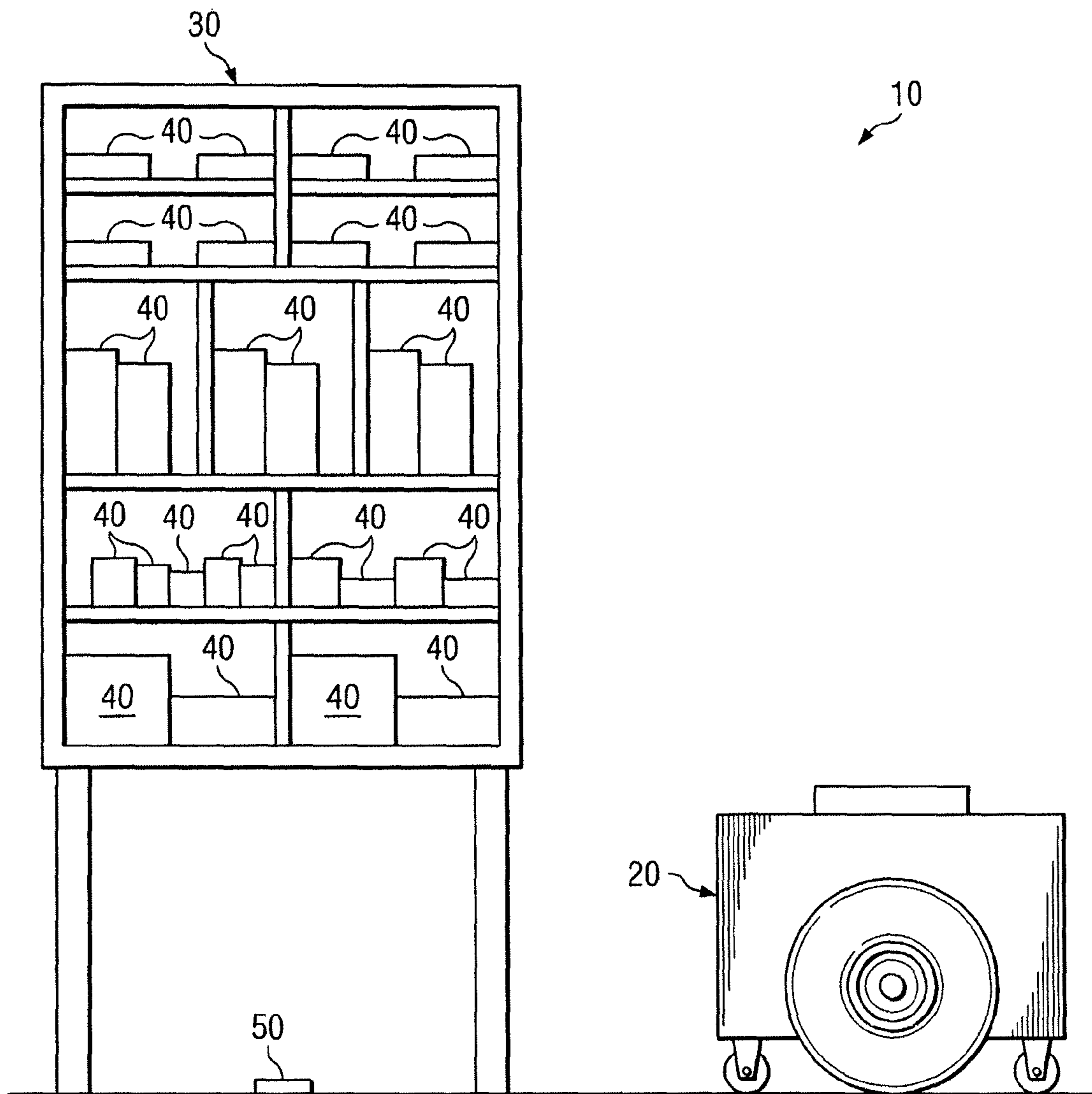


FIG. 1

FIG. 2A

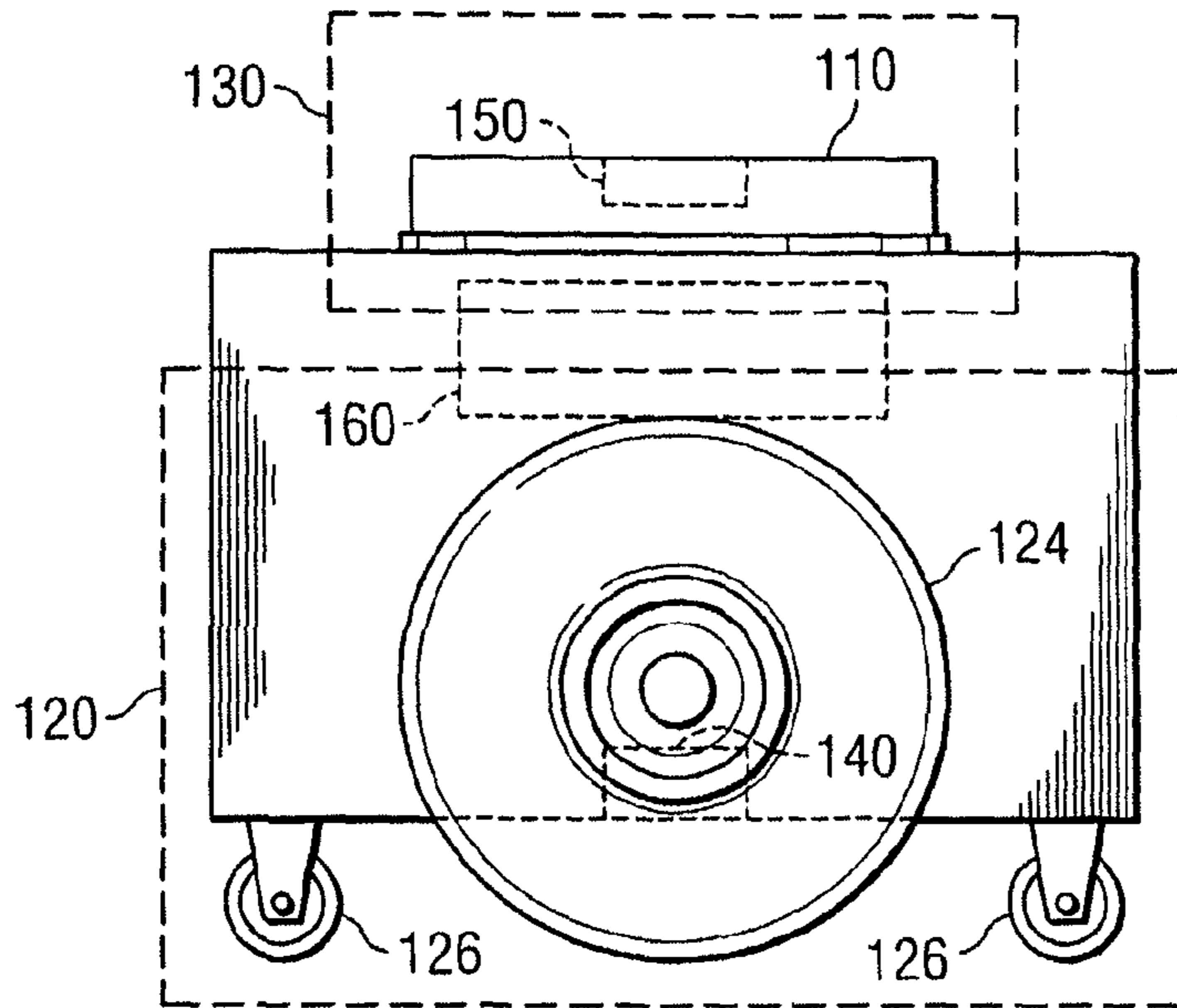
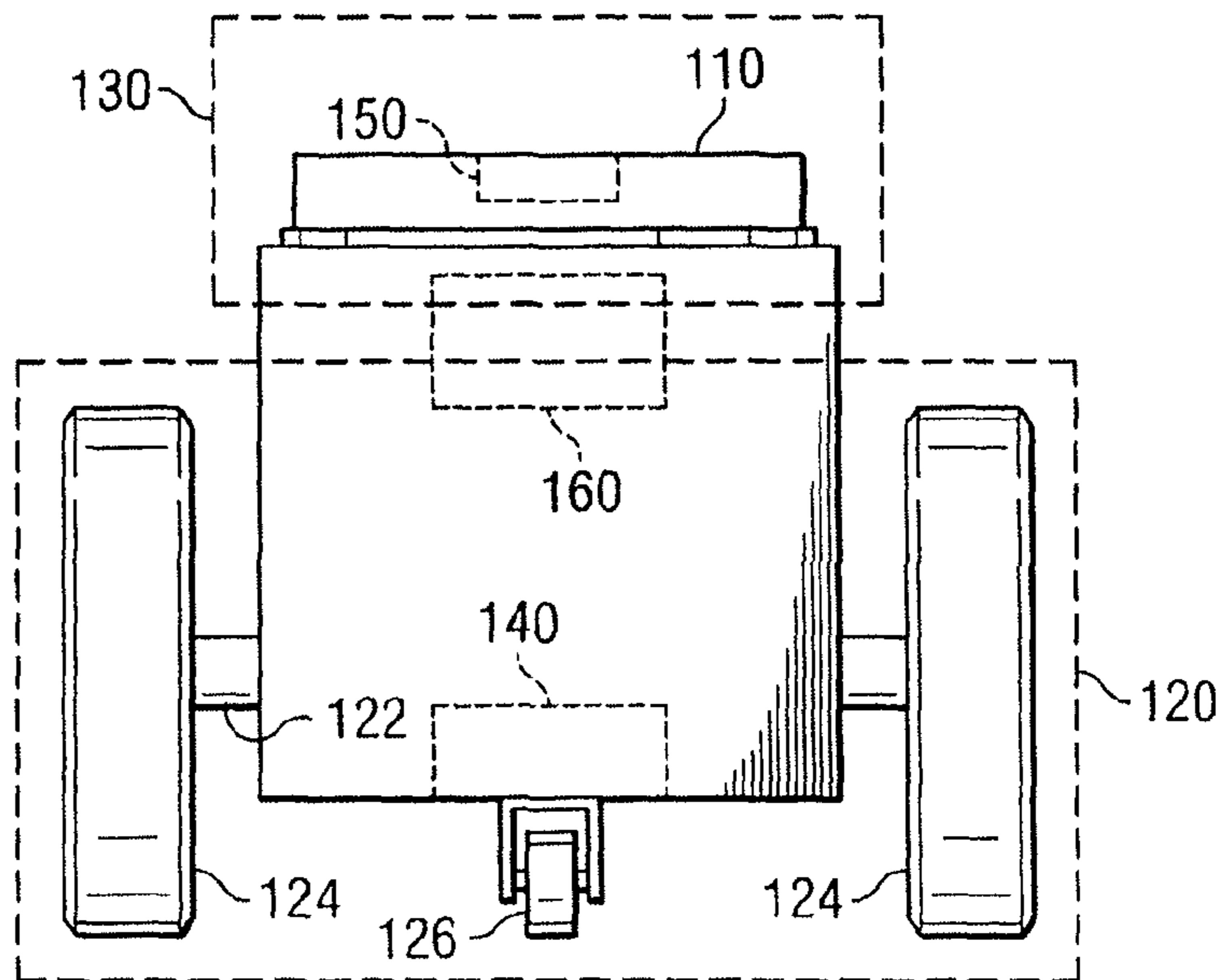


FIG. 2B



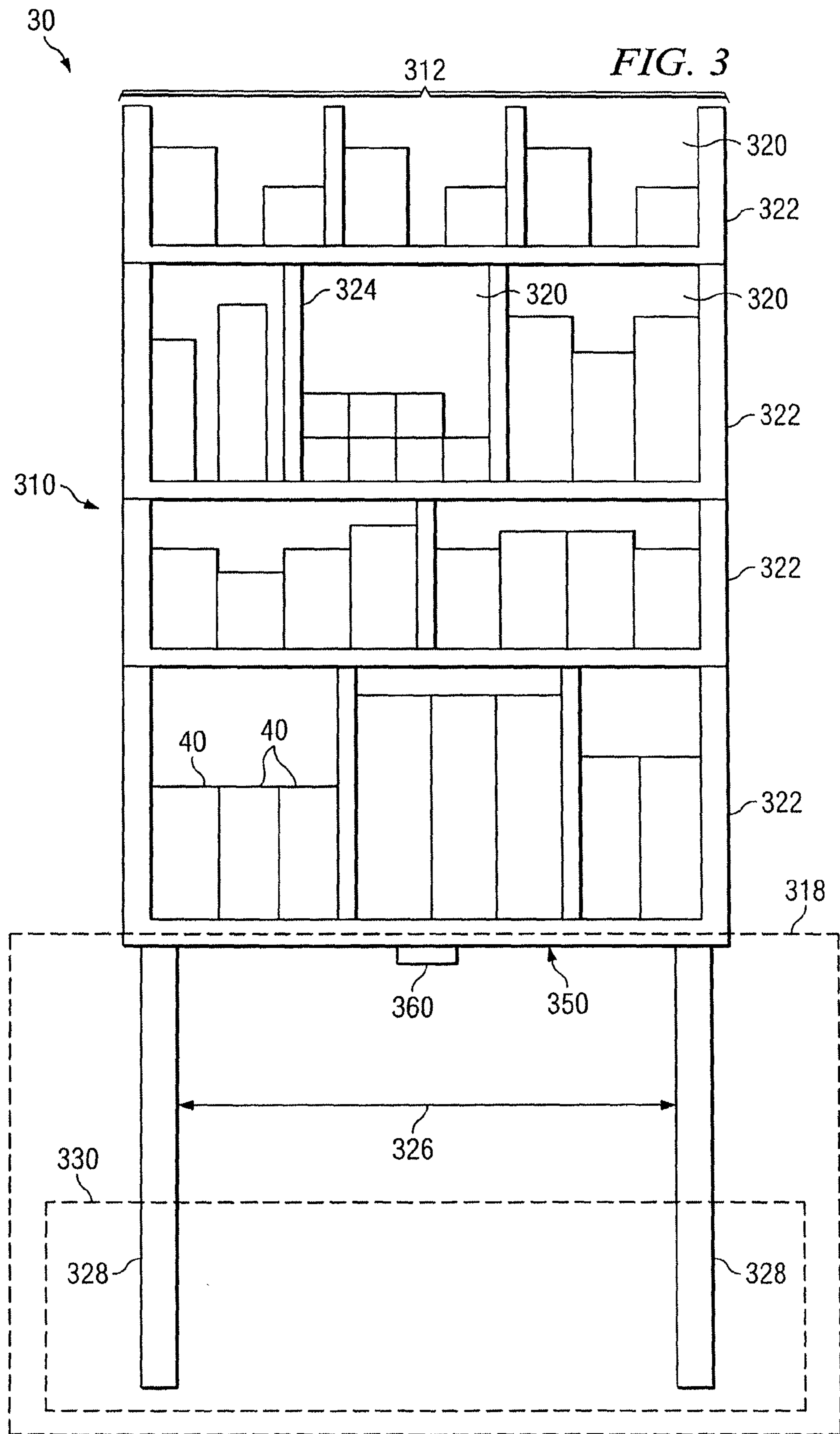


FIG. 4A

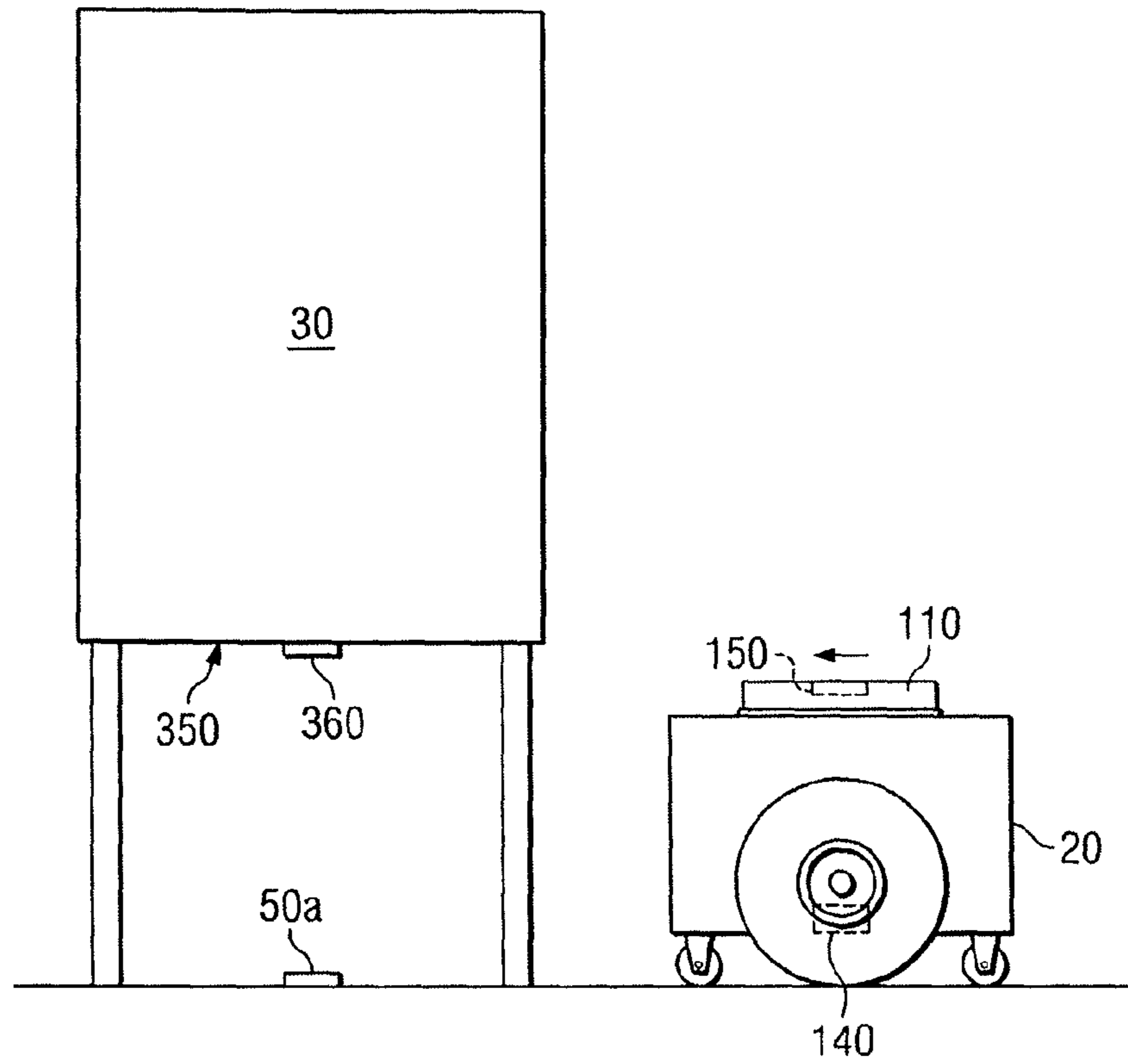


FIG. 4B

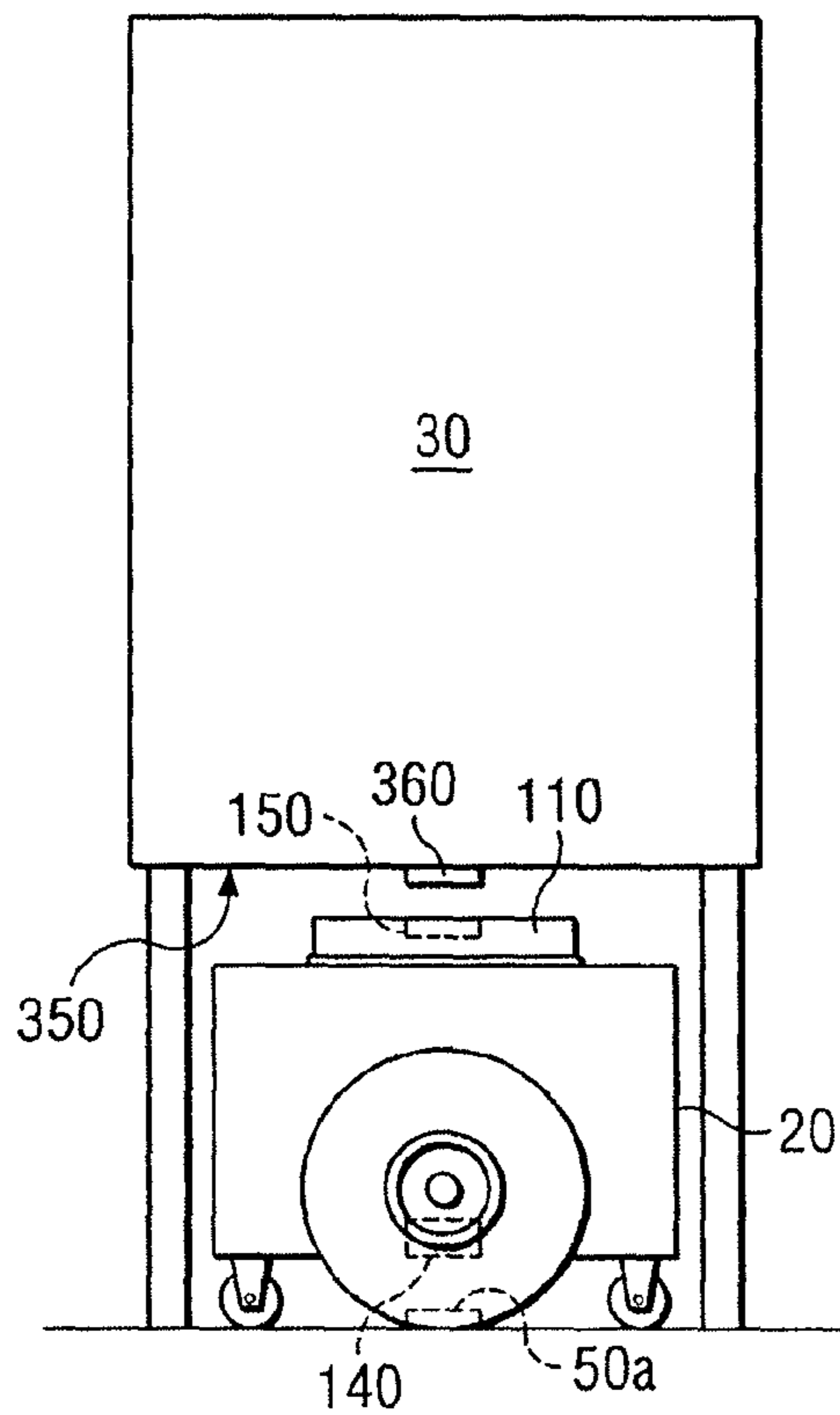


FIG. 4C

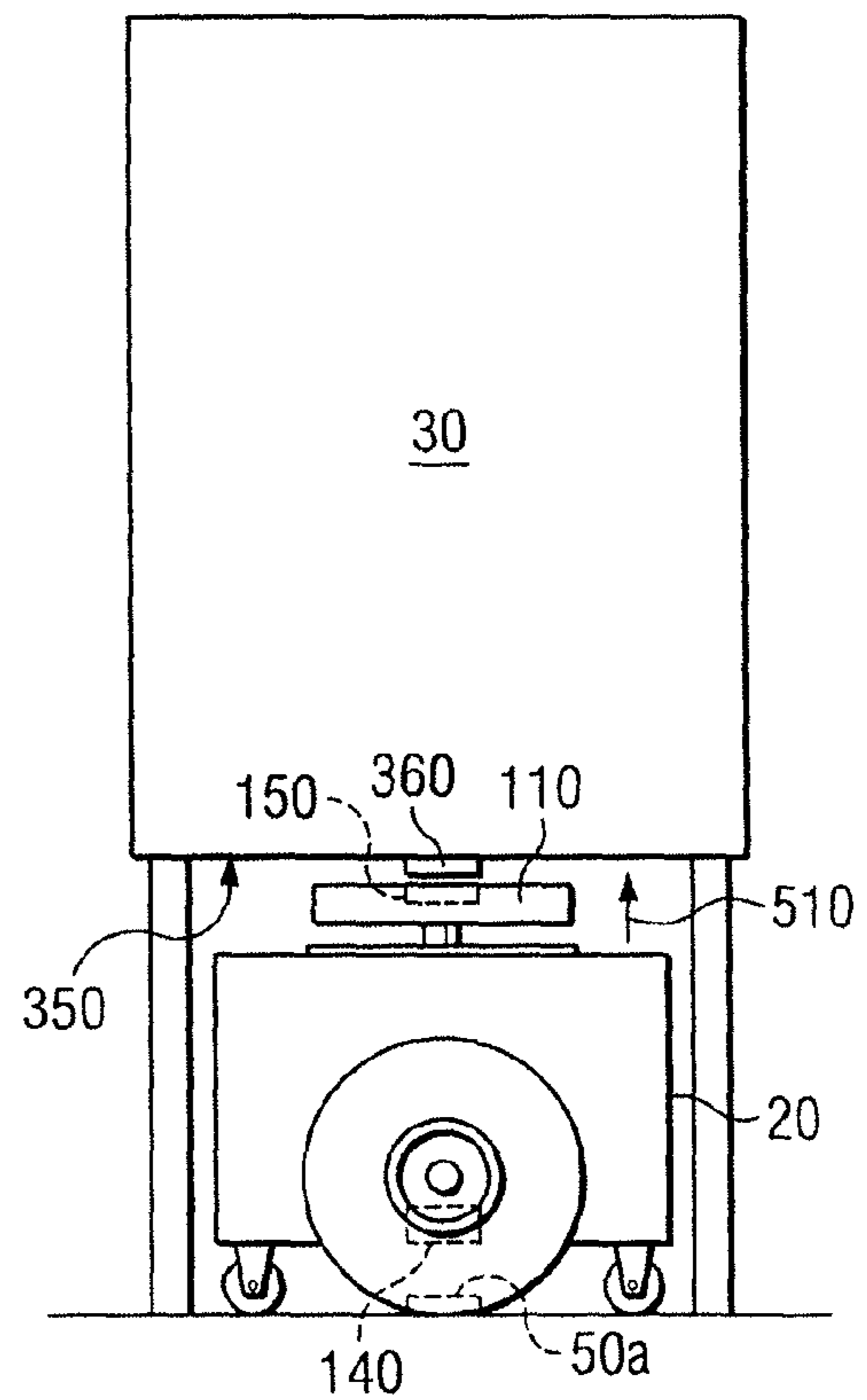


FIG. 4D

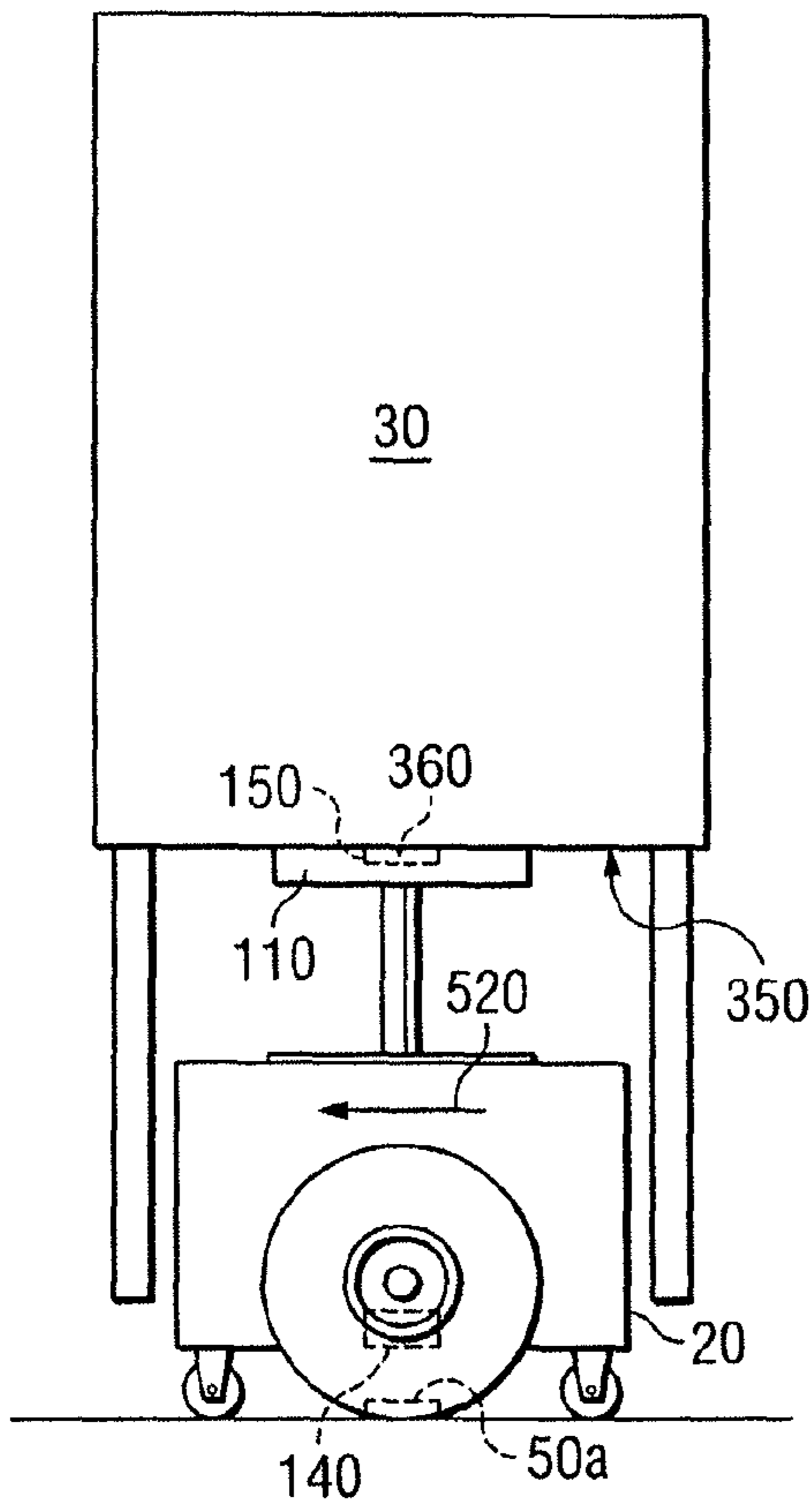


FIG. 4E

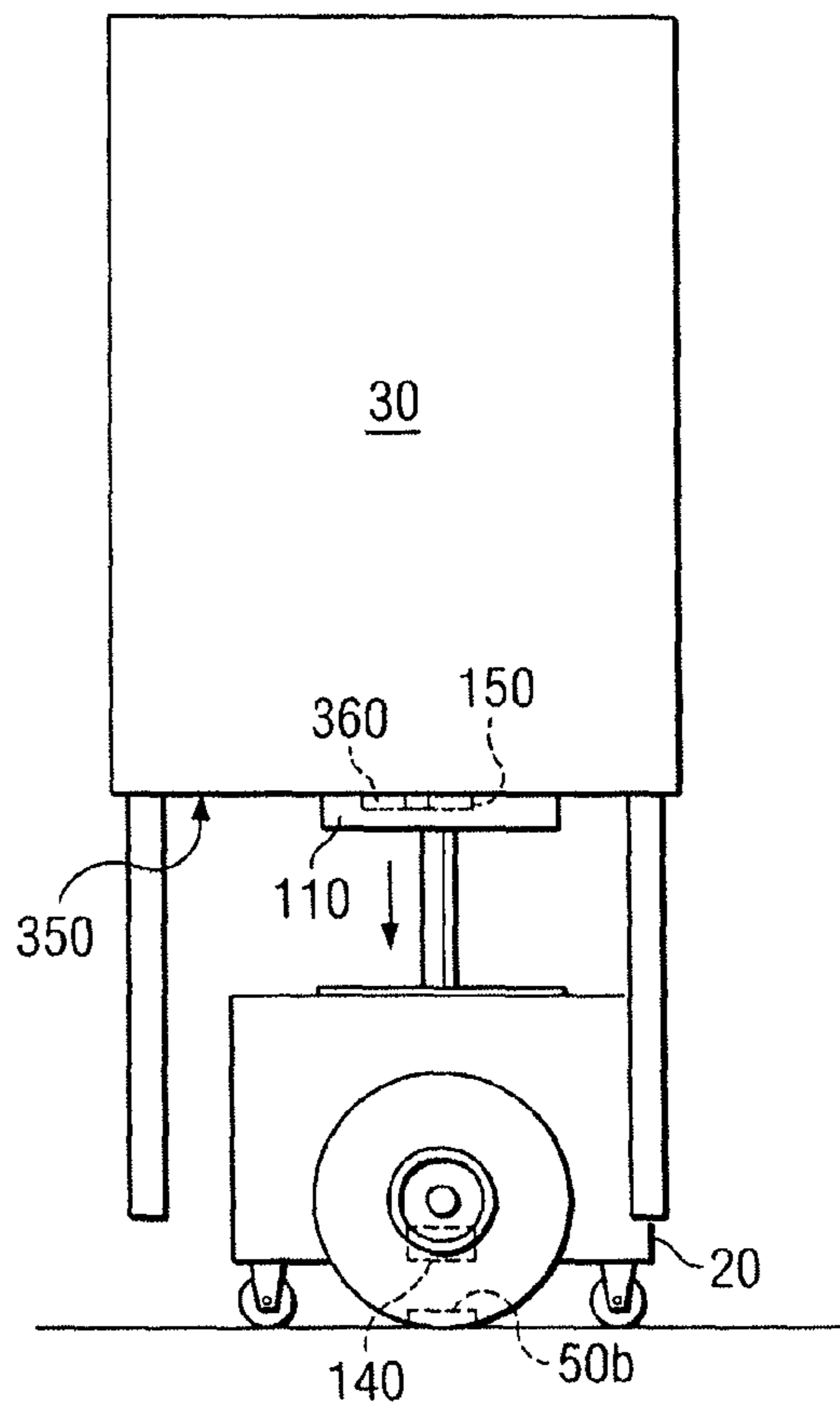


FIG. 4F

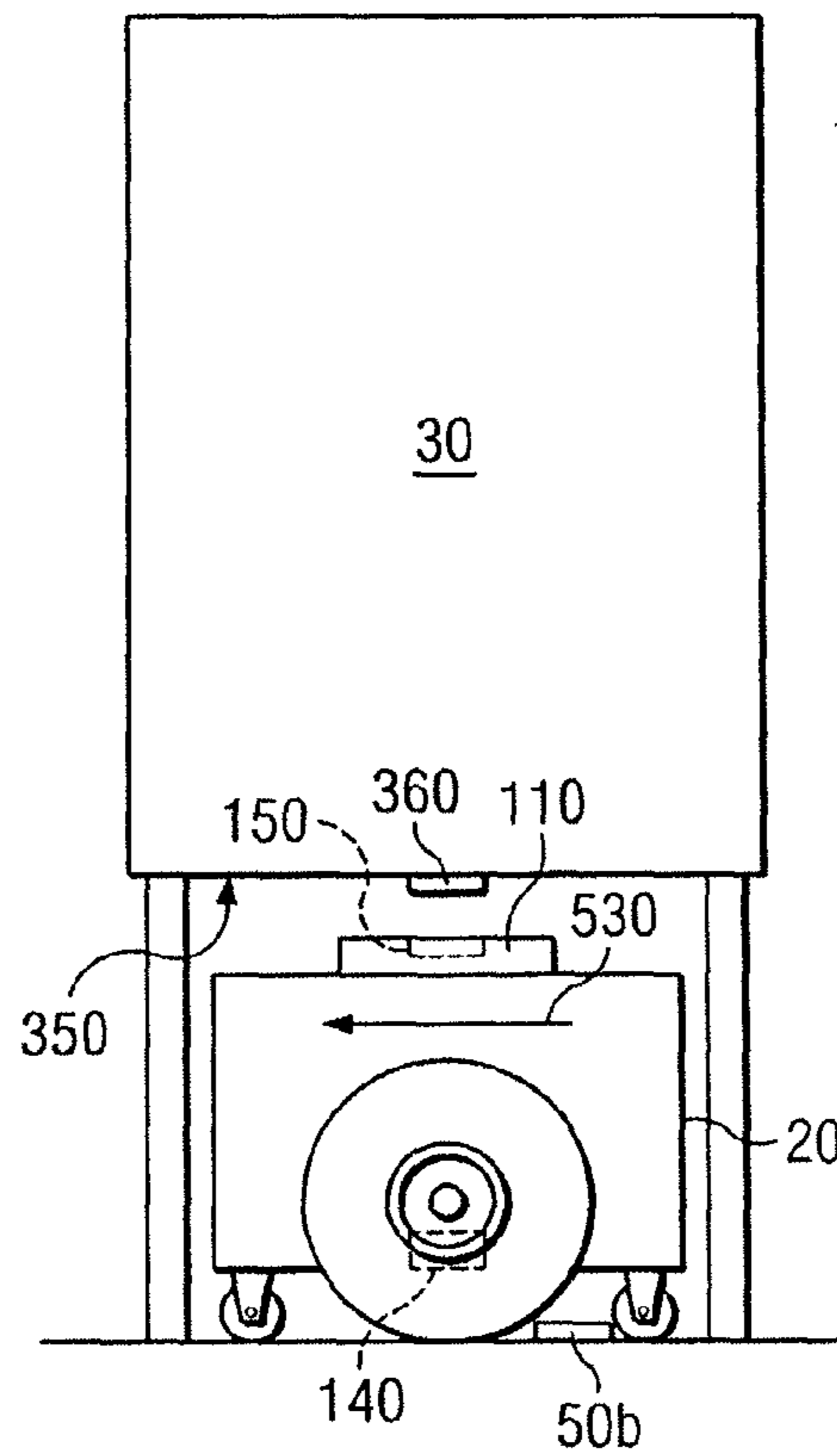


FIG. 4G

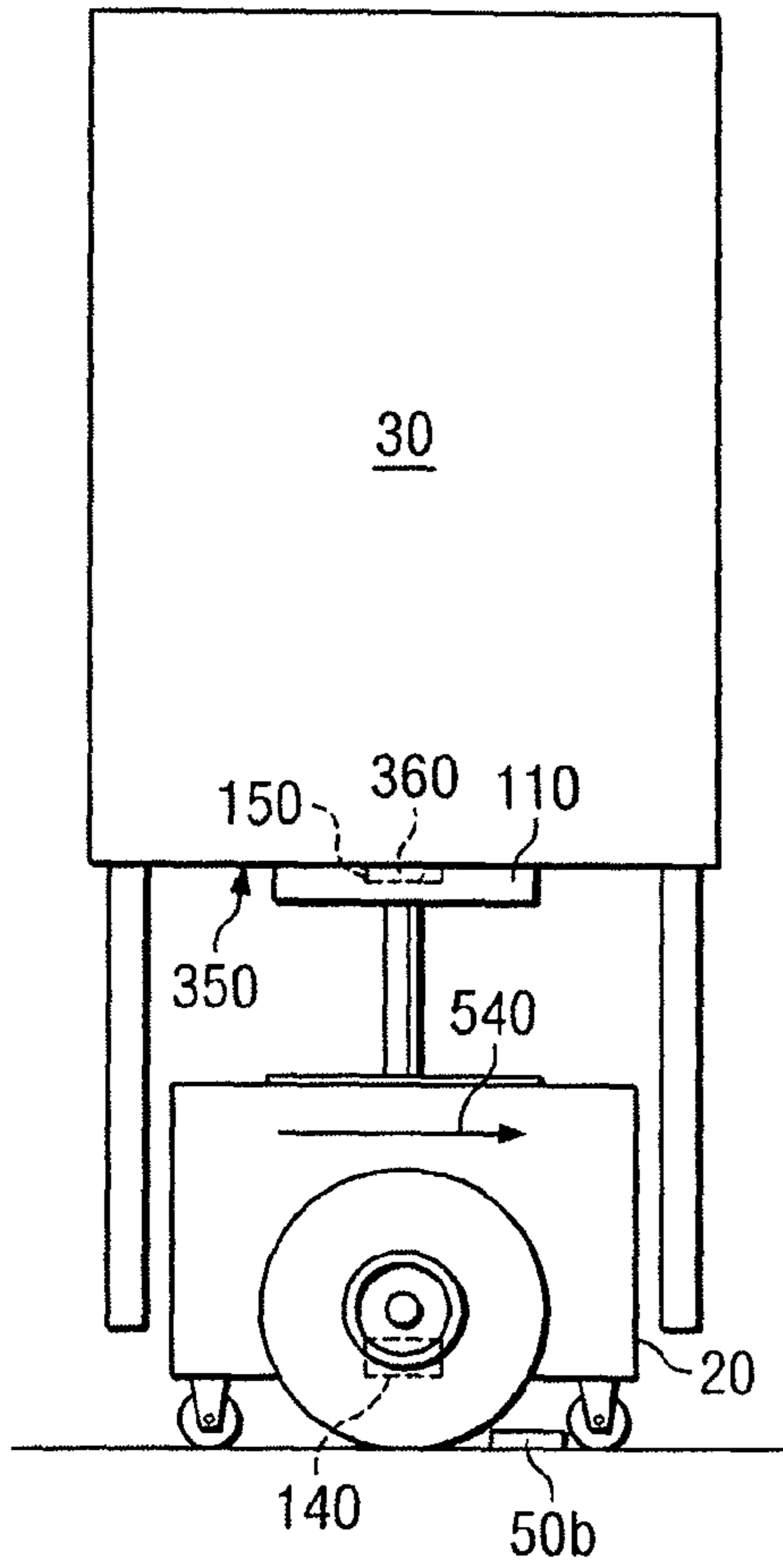
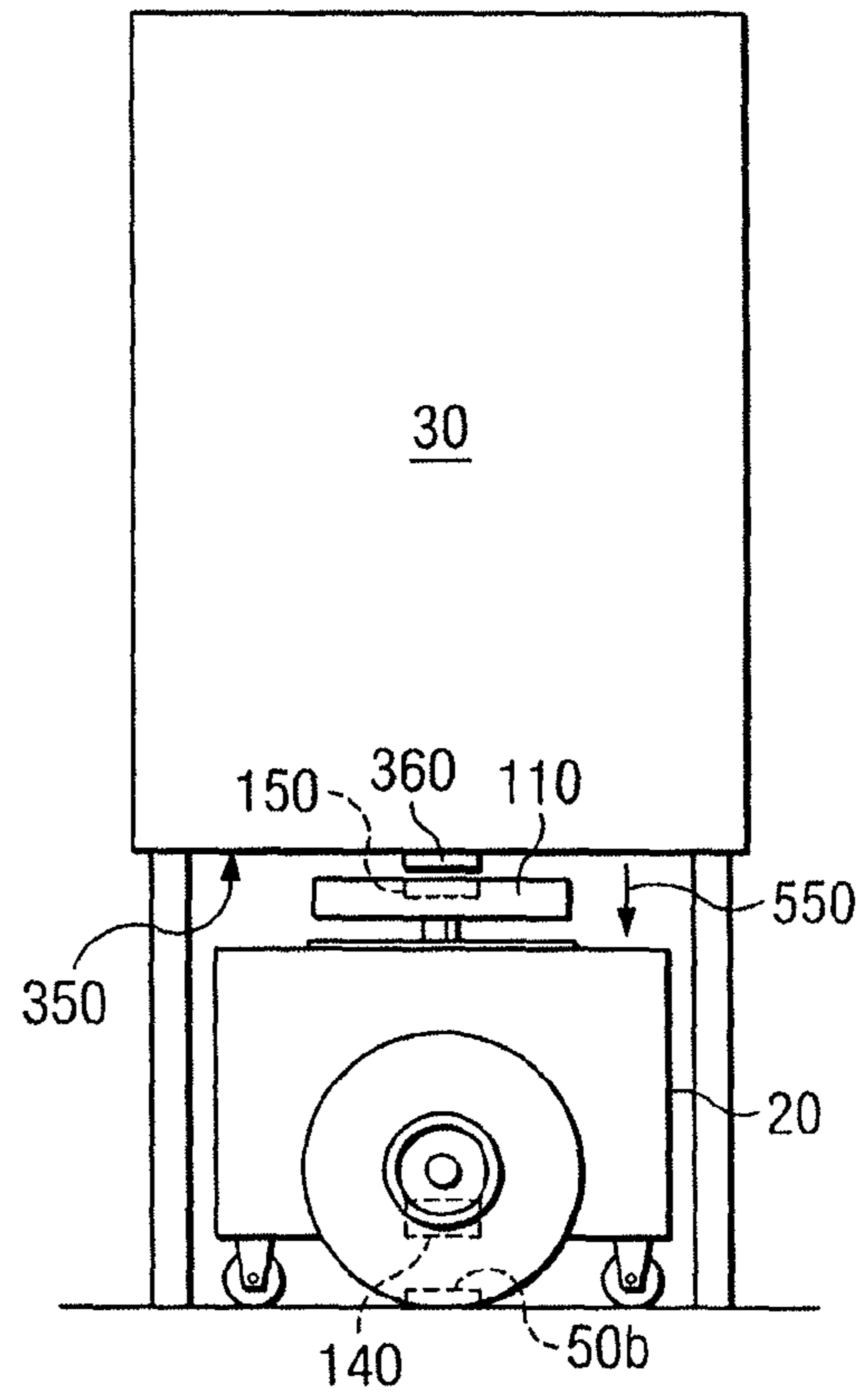
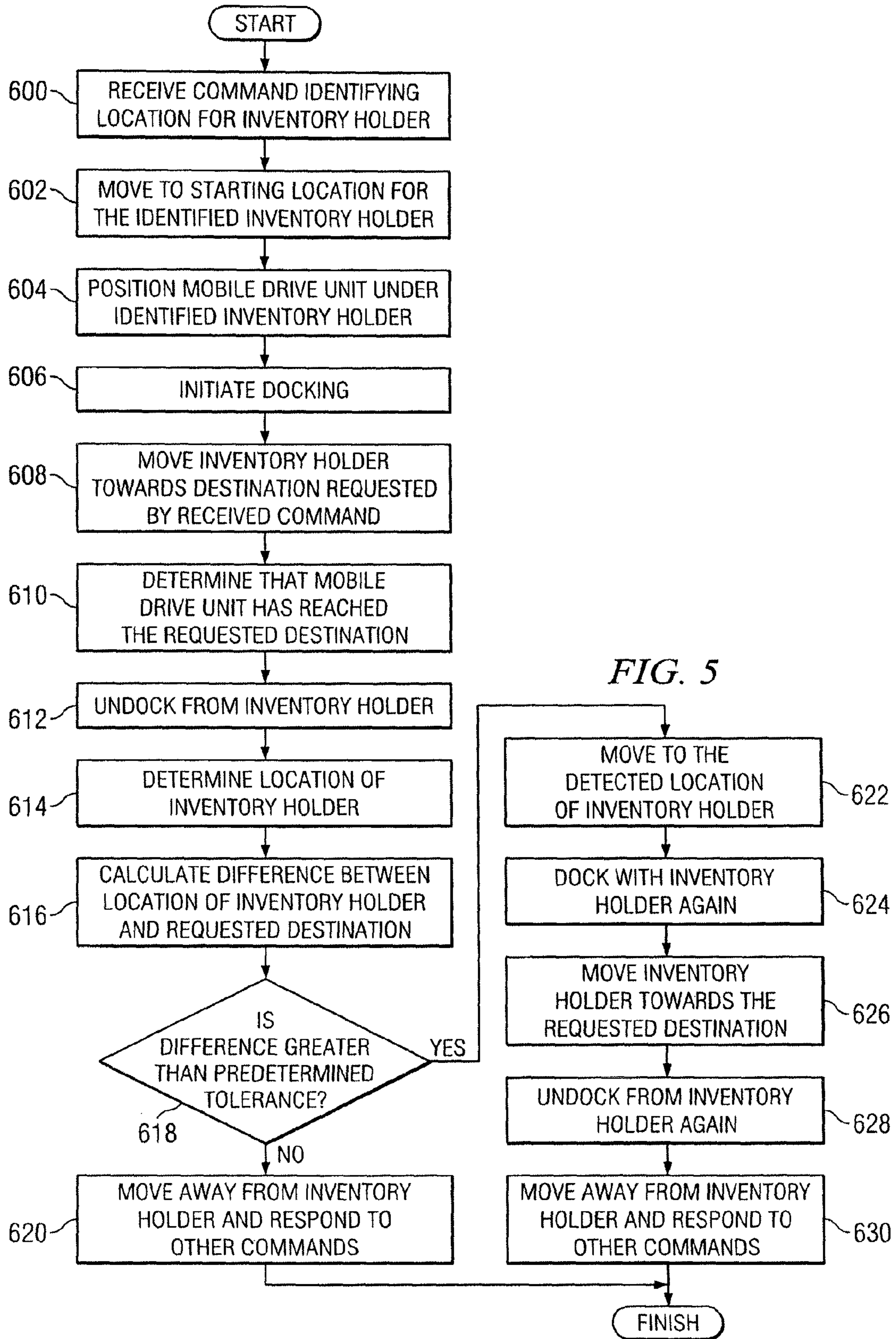
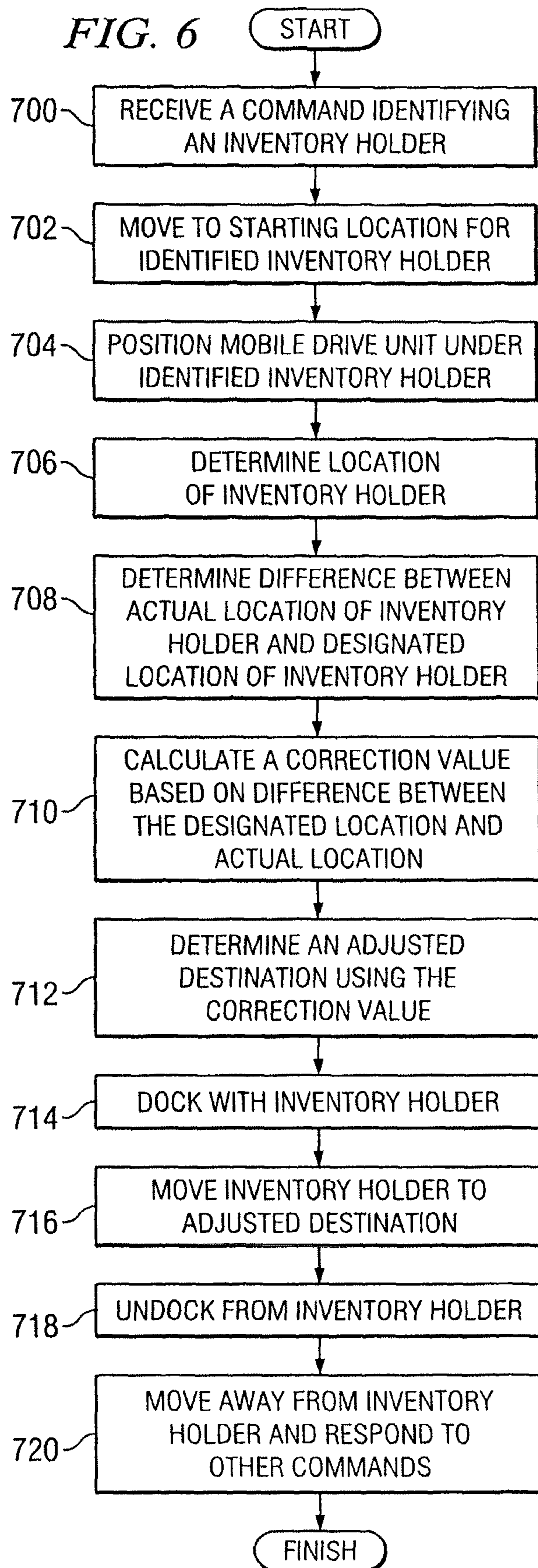
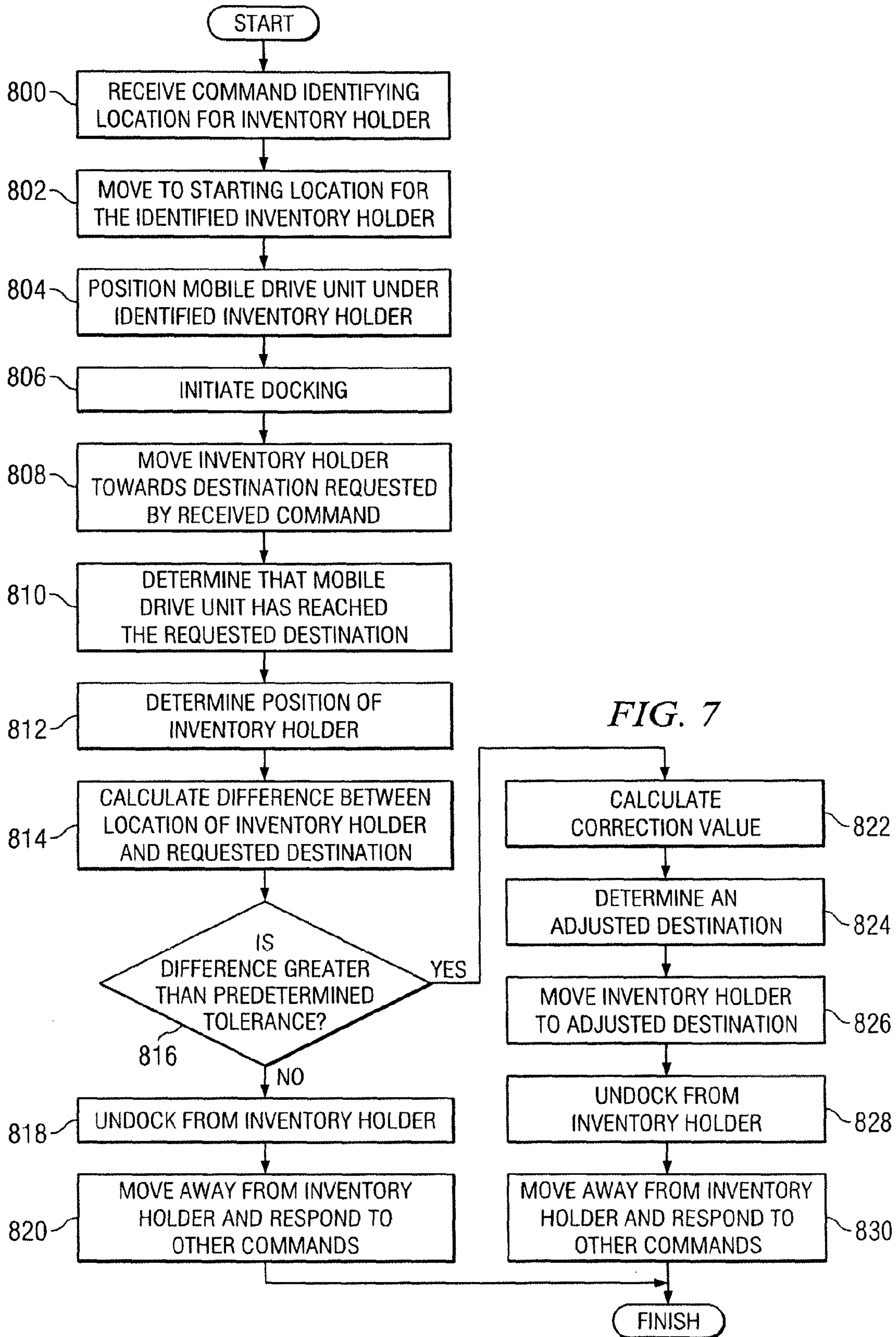


FIG. 4H









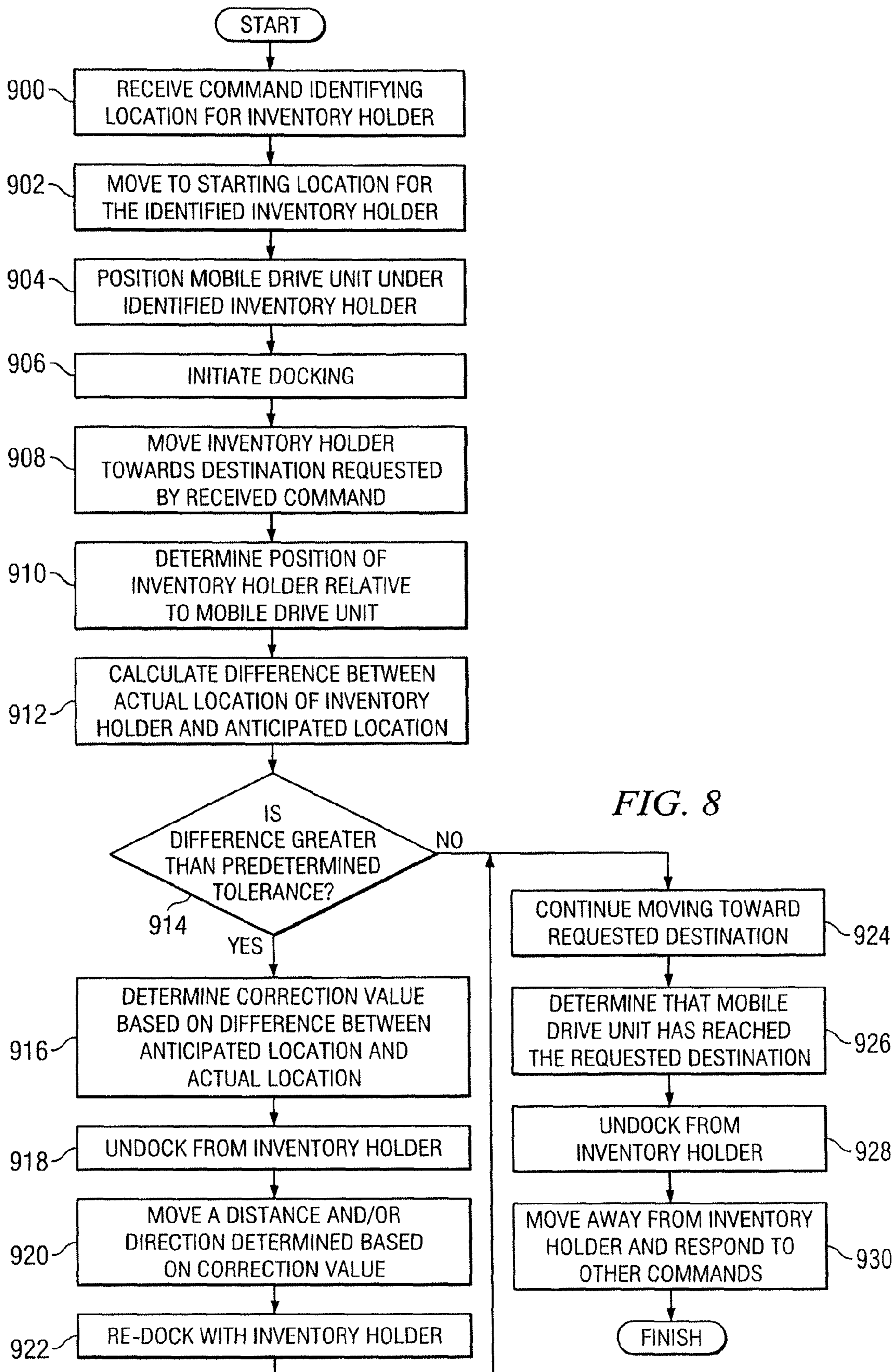


FIG. 8

1

METHOD AND SYSTEM FOR TRANSPORTING INVENTORY ITEMS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/553,024 entitled "Method and System for Transporting Inventory Items," filed Jul. 19, 2012 which is a continuation of U.S. patent application Ser. No. 12/890,197, entitled "Method and System for Transporting Inventory Items," which was filed Sep. 24, 2010, now U.S. Pat. No. 8,280,546, which is a divisional of U.S. patent application Ser. No. 11/423,294, entitled "Method and System for Transporting Inventory Items," which was filed on Jun. 9, 2006, now U.S. Pat. No. 7,826,919, all of which are hereby incorporated by reference.

TECHNICAL FIELD OF THE INVENTION

This invention relates in general to inventory systems, and more particularly, to a method and system for transporting inventory items within an inventory system.

BACKGROUND OF THE INVENTION

Modern inventory systems, such as those in mail-order and e-commerce warehouses, airport luggage systems, and custom-order manufacturing facilities, face significant challenges in providing fast, accurate responses to requests for inventory items. In recent years, automation has improved the speed and efficiency of storing and retrieving inventory items within such systems. However, automated systems can be extremely vulnerable to operational errors. In particular, when components within an automated system deviate from their anticipated operation, errors may be introduced. Correcting such errors may require manual intervention on the part of a human operator, thereby limiting the benefits of automation.

SUMMARY OF THE INVENTION

In accordance with the present invention, the disadvantages and problems associated with inventory systems have been substantially reduced or eliminated. In particular, a mobile inventory system is provided that supports techniques for automatic correction of particular types of operational errors.

In accordance with one embodiment of the present invention, a system for transporting inventory items includes an inventory holder and a mobile drive unit. The inventory holder is capable of storing inventory items. The mobile drive unit is capable of moving to a first point with the inventory holder at least one of coupled to and supported by the mobile drive unit. The mobile drive unit is additionally capable of determining a location of the inventory holder and calculating a difference between the location of the inventory holder and the first point. The mobile drive unit is then capable of determining whether the difference is greater than a predetermined tolerance. In response to determining that the difference is greater than the predetermined tolerance, the mobile drive unit is also capable of moving to a second point, docking with the inventory holder, and moving the mobile drive unit and the inventory holder to the first point.

In accordance with another embodiment of the present invention, a method for transporting inventory items

2

includes moving a mobile drive unit to a first point while an inventory holder is at least one of coupled to and supported by the mobile drive unit. Additionally, the method includes determining a location of the inventory holder and calculating a difference between the location of the inventory holder and the first point. The method also includes then determining whether the difference is greater than a predetermined tolerance. In response to determining that the difference is greater than the predetermined tolerance, the method further includes moving the mobile drive unit to a second point, docking the mobile drive unit with the inventory holder, and moving the mobile drive unit and the inventory holder to the first point.

Technical advantages of certain embodiments of the present invention include an inventory management system that is easily scalable, that can be easily adjusted to manage inventory items of varying types, sizes and shapes, and that can be operated with minimal human intervention. Additionally, particular embodiments of the present invention may support automated verification and correction of the placement of inventory holders by mobile drive units and/or other navigational features that limit the number of errors introduced by the operation of the mobile drive units.

Other technical advantages of the present invention will be readily apparent to one skilled in the art from the following figures, descriptions, and claims. Moreover, while specific advantages have been enumerated above, various embodiments may include all, some, or none of the enumerated advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and its advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates an inventory storage system according to a particular embodiment;

FIGS. 2A and 2B represents a cross-sectional diagram of a mobile drive unit according to a particular embodiment;

FIG. 3 illustrates the contents of an inventory holder according to a particular embodiment;

FIGS. 4A-4H show operation of various components of the mobile drive unit and the inventory holder during docking, movement, and undocking; and

FIG. 5 is a flowchart illustrating certain aspects of the operation of particular embodiments of mobile drive unit;

FIG. 6 is a flowchart illustrating other aspects of the operation of particular embodiments of mobile drive unit;

FIG. 7 is a flowchart illustrating yet other aspects of the operation of particular embodiments of mobile drive unit; and

FIG. 8 is a flowchart illustrating yet other aspects of the operation of particular embodiments of mobile drive unit.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates an inventory system 10 for storing, sorting, and retrieving inventory items 40 that includes a mobile drive unit 20 and an inventory holder 30. Inventory holder 30 stores multiple inventory items 40 of various item types. Mobile drive unit 20 moves inventory holder 30 between designated points within a workspace associated with inventory system 10.

Mobile drive unit 20 is capable of moving within the workspace and may include any appropriate components for

propelling itself and navigating to a particular destination within the workspace. Additionally, mobile drive unit **20** may dock with inventory holder **30** in any appropriate manner so that inventory holder **30** is coupled to and/or supported by mobile drive unit **20** when mobile drive unit **20** is docked with inventory holder **30**. When docked to inventory holder **30**, mobile drive unit **20** is also capable of propelling and/or otherwise moving inventory holder **30**. Mobile drive unit **20** may include any appropriate components for docking with inventory holder **30** and for maneuvering inventory holder **30** while inventory holder **30** is docked with mobile drive unit **20**. The components of a particular embodiment of mobile drive unit **20** are described in greater detail below with respect to FIGS. **2A** and **2B**. Although FIG. **1** shows, for the sake of simplicity, only a single mobile drive unit **20**, inventory system **10** may include any appropriate number of mobile drive units. As a result, mobile drive unit **20** may represent one of several mobile drive units **20** moving inventory holders **30** in inventory system **10**.

Inventory holder **30** stores inventory items **40**. In particular embodiments, inventory holder **30** includes multiple storage bins with each storage bin capable of holding inventory items **40**. Additionally, in particular embodiments, inventory items **40** may also hang from hooks or bars within or on inventory holder **30**. In general, inventory holder **30** may store inventory items **40** in any appropriate manner within inventory holder **30** and/or on the external surface of inventory holder **30**. Inventory holder **30** is capable of being rolled, carried, or otherwise moved by mobile drive unit **20**. The components of a particular embodiment of inventory holder **30** are described in greater detail below with respect to FIG. **3**. Although FIG. **1** shows, for the sake of simplicity, only a single inventory holder **30**, inventory system **10** may include any appropriate number of inventory holders. As a result, inventory holder **30** may represent one of several inventory holders **30** storing inventory items **40** in inventory system **10**.

Inventory items **40** represent any items, material, or animate or inanimate objects suitable for storage, retrieval, delivery, sortation, and/or routing in an automated inventory, warehouse, manufacturing, and/or parts-handling system. As one example, inventory items **40** may represent items of merchandise stored in a warehouse. Mobile drive unit **20** may retrieve a specified inventory holder **30** containing particular inventory items **40** associated with a customer order to be packed for delivery to a customer or other party.

As another example, inventory items **40** may represent luggage stored in a luggage facility of an airport. Mobile drive unit **20** may retrieve inventory holder **30** containing luggage to be transported, tracked, and/or otherwise processed according to particular policies. This may include selecting particular items of luggage for explosives screening, moving items of luggage associated with a flight that has switched gates, or removing luggage items belonging to passengers who have missed the flight.

As yet another example, inventory items **40** may represent individual components of a manufacturing kit. More specifically, the components may represent components intended for inclusion in an assembled product, such as computer components for a customized computer system. In such an embodiment, mobile drive unit **20** may retrieve particular components identified by a specification associated with a customer order.

As yet another example, inventory items **40** may represent people. For example, in a hospital setting, inventory items **40** may represent beds containing particular patients. Thus,

inventory system **10** may be configured to provide a safe, effective system for moving hospital beds that limits the potential for injury to patients and reduces the possibility of mistakes arising from human error. In general, however, inventory items **40** may be any suitable items appropriate for storage in any appropriate form of inventory holder **30**, as described below.

In operation, mobile drive unit **20** is capable of moving between points within a workspace associated with inventory system **10** and, when coupled to inventory holder **30**, of transporting inventory holder **30** between locations within the workspace. Mobile drive unit **20** may determine the movement of mobile drive unit **20** autonomously and/or based on commands received by mobile drive unit **20**. For example, in particular embodiments, mobile drive unit **20** may receive information that identifies destinations for mobile drive unit **20** from a management device of inventory system **10**, from an operator of inventory system **10**, or any other suitable party or device. Mobile drive unit **20** may receive the information through a wireless interface, over a wired connection, or using any other suitable components to communicate with an operator or management device of inventory system **10**. In general, however, movement of mobile drive unit **20** may, depending on the configuration of mobile drive unit **20** and inventory system **10**, be controlled, in whole or in part, by mobile drive unit **20**, or any appropriate external devices or parties.

For the sake of simplicity, however, the remainder of this description assumes that mobile drive unit **20** wirelessly receives orders, data, instructions, commands, or information structured in any other appropriate form, referred to here as a “command” or “commands,” from a remote component of inventory system **10**. These commands identify a particular inventory holder **30** to be moved by mobile drive unit **20** and/or a current location for that inventory holder **30**, and a destination for that inventory holder **30**. Mobile drive unit **20** then controls operation of motors, wheels, and/or other components of mobile drive unit **20** to move mobile drive unit **20** and/or inventory holder **30**.

In response to receiving such a command, mobile drive unit **20** moves to a storage location identified by the command. Mobile drive unit **20** may then dock with identified inventory holder **30**. Mobile drive unit **20** may dock with inventory holder **30** in any appropriate manner so that inventory holder **30** is coupled to and/or supported by mobile drive unit **20** when mobile drive unit **20** is docked with inventory holder **30**. For example, in particular embodiments, mobile drive unit **20** docks with inventory holder **30** by positioning itself beneath inventory holder **30** and raising a docking head of mobile drive unit **20** until the docking head lifts inventory holder **30** off the ground. As a result, in such embodiments, mobile drive unit **20** may support all or a portion of the weight of inventory holder **30** when mobile drive unit **20** is docked with inventory holder **30**. Additionally, in particular embodiments, one or more components of mobile drive unit **20** may grasp, connect to, interlock with, or otherwise interact with one or more components of inventory holder **30** to form a physical coupling between mobile drive unit **20** and inventory holder **30**. For example, in particular embodiments, a docking head of mobile drive unit **20** may include one or more spines that fit within apertures of inventory holder **30** when mobile drive unit **20** docks with inventory holder **30**, allowing mobile drive unit **20** to maneuver inventory holder **30** by applying force to inventory holder **30**.

After docking with inventory holder **30**, mobile drive unit **20** may move inventory holder **30** to a second location, such

5

as an inventory station, where appropriate inventory items **40** may be selected from inventory holder **30** and packed for shipping or where inventory items **40** may be added to inventory holder **30** to replenish the supply of inventory items **40** available in inventory system **10**. In a particular embodiment, mobile drive unit **20** may provide sufficient power to propel both mobile drive unit **20** and inventory holder **30**. In alternative embodiments, inventory holder **30** may provide additional power, such as through the operation of motorized wheels on inventory holder **30**, to assist mobile drive unit **20** in propelling inventory holder **30** to the second location.

Depending on the configuration and characteristics of mobile drive unit **20** and inventory system **10**, mobile drive unit **20** may move inventory holder **30** using a variety of appropriate methods. In a particular embodiment, mobile drive unit **20** is capable of moving inventory holder **30** along a two-dimensional grid, combining movement along straight-line segments with ninety-degree rotations and arcing paths to transport inventory holder **30** from the first location to the second location. Additionally, while moving, mobile drive unit **20** may use fixed objects located in the workspace as reference points to assist in navigation. For example, in particular embodiments, inventory system **10** includes multiple fiducial marks **50**. Mobile drive unit **20** may be configured to detect fiducial marks **50** and to determine the location of mobile drive unit **20** and/or measure its movement based on the detection of fiducial marks **50**.

After mobile drive unit **20** arrives at the second location, mobile drive unit **20** may perform appropriate operations to facilitate access to inventory items **40** stored in inventory holder **30**. For example, mobile drive unit **20** may rotate inventory holder **30** to present a particular face of inventory holder **30** to an operator of inventory system **10** or other suitable party, such as a packer selecting inventory items **40** from inventory holder **30**. Mobile drive unit **20** may also undock from inventory holder **30**. Alternatively, instead of undocking at the second location, mobile drive unit **20** may transport inventory holder **30** back to the first location or to a third location after any appropriate actions have been taken involving inventory items **40**. For example, after a packer has removed particular inventory items **40** from inventory holder **30**, mobile drive unit **20** may return inventory holder **30** to its original storage location, a new storage location, or another inventory station. Mobile drive unit **20** may then undock from inventory holder **30** at this new location.

Because inventory system **10**, in particular embodiments, is at least partially automated, it may be desirable for the location of inventory holder **30** to be precisely controlled so that mobile drive units **20** can properly locate and interact with inventory holders **30**. As used in this description and the claims that follow, unless otherwise indicated the "location" of an inventory holder **30** or mobile drive unit **20** may represent an absolute or relative measurement of the location, position, and/or orientation of the relevant device. As a result, before undocking from inventory holder **30**, mobile drive unit **20** may attempt to align itself with a reference point within the workspace so that inventory holder **30** will be properly situated for subsequent transportation and/or to prevent collision with other devices moving within the workspace. For example, mobile drive unit **20** may attempt to align itself with a particular fiducial mark **50** before undocking from inventory holder **30**.

While mobile drive unit **20** is transporting inventory holder **30**, however, the location of inventory holder **30** relative to mobile drive unit **20** may shift slightly. This

6

shifting may occur as the result of slippage between docking surfaces of mobile drive unit **20** and inventory holder **30**, vibration during transport, or any other incident that may alter the location of inventory holder **30** relative to mobile drive unit **20**. As a result of this slippage, mobile drive unit's attempt to align itself with an appropriate reference point before undocking may not be sufficient to ensure that inventory holder **30** is properly aligned with that reference point after undocking.

Consequently, in particular embodiments, mobile drive unit **20** may be configured to perform certain operations, as described in greater detail below, to detect and correct misalignments of an inventory holder **30** after that inventory holder **30** has been moved within the workspace. More specifically, in particular embodiments, mobile drive unit **20** may determine the difference between the location of a particular inventory holder **30** and an anticipated, intended, and/or requested location of the inventory holder **30**. Mobile drive unit **20** may then take certain actions to reduce or eliminate this deviation, immediately following undocking from inventory holder **30**, prior to a subsequent docking with inventory holder **30**, or at any other appropriate time during the course of operation. FIGS. 4A-4H illustrate operation of a particular embodiment of mobile drive unit **20** in correcting a misalignment of inventory holder **30**. Additionally, FIGS. 5 and 6 are flowcharts describing the operation of particular embodiments of mobile drive unit **20** in correcting misalignments in inventory holder **30**.

The implementation of such correction techniques may, in particular embodiments, allow greater precision in the placement of inventory holders **30** and facilitate a greater degree of automation in inventory system **10**. Additionally, in particular embodiments, implementation of such techniques may also reduce operational errors in inventory system **10**, permit the use of a smaller workspace, and/or prevent improperly positioned inventory holders **30** from being damaged by mobile drive units **20** and other components moving in the workspace of inventory system **10**. As a result, particular embodiments of mobile drive unit **20** may provide multiple benefits. Nonetheless, although particular embodiments of mobile drive unit **20** may provide such benefits, alternative embodiments may provide some, none, or all of these benefits.

FIGS. 2A and 2B include a front and side view of a particular embodiment of mobile drive unit **20**. Mobile drive unit **20** includes a docking head **110**, a drive module **120**, a docking actuator **130**, and a control module **160**. Additionally, mobile drive unit **20** may include one or more sensors configured to detect or determine the location of mobile drive unit **20**, inventory holder **30**, and/or other appropriate elements of inventory system **10**. In the illustrated embodiment, mobile drive unit **20** includes a position sensor **140** and a holder sensor **150**.

Docking head **110**, in particular embodiments of mobile drive unit **20**, couples mobile drive unit **20** to inventory holder **30** and/or supports inventory holder **30** when mobile drive unit **20** is docked to inventory holder **30**. Docking head **110** may additionally allow mobile drive unit **20** to maneuver inventory holder **30**, such as by lifting inventory holder **30**, propelling inventory holder **30**, rotating inventory holder **30**, and/or moving inventory holder **30** in any other appropriate manner. Docking head **110** may also include any appropriate combination of components, such as ribs, spikes, and/or corrugations, to facilitate such manipulation of inventory holder **30**. For example, in particular embodiments, docking head **110** may include a high-friction portion that abuts a portion of inventory holder **30** while mobile

drive unit **20** is docked to inventory holder **30**. In such embodiments, frictional forces created between the high-friction portion of docking head **110** and a surface of inventory holder **30** may induce translational and rotational movement in inventory holder **30** when docking head **110** moves and rotates, respectively. As a result, mobile drive unit **20** may be able to manipulate inventory holder **30** by moving or rotating docking head **110**, either independently or as a part of the movement of mobile drive unit **20** as a whole.

Drive module **120** propels mobile drive unit **20** and, when mobile drive unit **20** and inventory holder **30** are docked, inventory holder **30**. Drive module **120** may represent any appropriate collection of components operable to propel drive module **120**. For example, in the illustrated embodiment, drive module **120** includes motorized axle **122**, a pair of motorized wheels **124**, and a pair of stabilizing wheels **126**. One motorized wheel **124** is located at each end of motorized axle **122**, and one stabilizing wheel **126** is positioned at each end of mobile drive unit **20**.

Docking actuator **130** moves docking head **110** towards inventory holder **30** to facilitate docking of mobile drive unit **20** and inventory holder **30**. Docking actuator **130** may also be capable of adjusting the position or orientation of docking head **110** in other suitable manners to facilitate docking. Docking actuator **130** may include any appropriate components, based on the configuration of mobile drive unit **20** and inventory holder **30**, for moving docking head **110** or otherwise adjusting the position or orientation of docking head **110**. For example, in the illustrated embodiment, docking actuator **130** includes a motorized shaft (not shown) attached to the center of docking head **110**. The motorized shaft is operable to lift docking head **110** as appropriate for docking with inventory holder **30**.

Drive module **120** may be configured to propel mobile drive unit **20** in any appropriate manner. For example, in the illustrated embodiment, motorized wheels **124** are operable to rotate in a first direction to propel mobile drive unit **20** in a forward direction. Motorized wheels **124** are also operable to rotate in a second direction to propel mobile drive unit **20** in a backward direction. In the illustrated embodiment, drive module **120** is also configured to rotate mobile drive unit **20** by rotating motorized wheels **124** in different directions from one another or by rotating motorized wheels **124** at different speed from one another.

Position sensor **140** represents one or more sensors, detectors, or other components suitable for determining the location of mobile drive unit **20** in any appropriate manner. For example, in particular embodiments, the workspace associated with inventory system **10** includes a number of fiducial marks that mark points on a two-dimensional grid that covers all or a portion of the workspace. In such embodiments, position sensor **140** may include a camera and suitable image- and/or video-processing components, such as an appropriately-programmed digital signal processor, to allow position sensor **140** to detect fiducial marks within the camera's field of view. Control module **160** may store location information that position sensor **140** updates as position sensor **140** detects fiducial marks. As a result, position sensor **140** may utilize fiducial marks to maintain an accurate indication of the location mobile drive unit **20** and to aid in navigation when moving within the workspace.

Holder sensor **150** represents one or more sensors, detectors, or other components suitable for detecting inventory holder **30** and/or determining, in any appropriate manner, the location of inventory holder **30**, as an absolute location or as a position relative to mobile drive unit **20**. Holder sensor **150**

may be capable of detecting a particular portion of inventory holder **30** or inventory holder **30** as a whole. For example, in particular embodiments, each inventory holder **30** in inventory system **10** includes a holder identifier that marks a predetermined location on that inventory holder **30**. In certain examples of such embodiments, mobile drive unit **20** and inventory holder **30** may also be configured so that, when mobile drive unit **20** moves beneath inventory holder **30**, mobile drive unit **20** is able to detect the holder identifier directly. In such embodiments, holder sensor **150** may include a camera and suitable image- and/or video-processing components, such as an appropriately-programmed digital signal processor, to allow holder sensor **150** to detect the holder identifier of a particular inventory holder **30** and to calculate the location of the inventory holder **30** based on this detection. As a result, mobile drive unit **20** may be configured to utilize these holder identifiers as reference points to aid in navigation when docking with or undocking from inventory holders **30**.

Control module **160** monitors and/or controls operation of drive module **120** and docking actuator **130**. Control module **160** may also receive information from sensors such as position sensor **140** and holder sensor **150** and adjust the operation of drive module **120**, docking actuator **130**, and/or other components of mobile drive unit **20** based on this information. Additionally, in particular embodiments, mobile drive unit **20** may be configured to communicate with a management device of inventory system **10** and control module **160** may receive commands transmitted to mobile drive unit **20** and communicate information back to the management device utilizing appropriate communication components of mobile drive unit **20**. Control module **160** may include any appropriate hardware and/or software suitable to provide the described functionality. In particular embodiments, control module **160** includes a general-purpose microprocessor programmed to provide the described functionality. Additionally, control module **160** may include all or portions of docking actuator **120**, drive module **130**, position sensor **140**, and/or holder sensor **150**, and/or share components with any of these elements of mobile drive unit **20**.

FIG. 3 illustrates inventory holder **30** in accordance with a particular embodiment. FIG. 3 illustrates the structure and contents of one side of inventory holder **30**. In a particular embodiment, inventory holder **30** may comprise any number of faces with similar or different structure. As illustrated, inventory holder **30** includes a frame **310**, a plurality of legs **328**, and docking surface **350**.

Frame **310** holds inventory items **40**. Frame **310** provides storage space for storing inventory items **40** external or internal to frame **310**. The storage space provided by frame **310** may be divided into a plurality of inventory bins **320**, each capable of holding inventory items **40**. Inventory bins **320** may include any appropriate storage elements, such as bins, compartments, or hooks.

In a particular embodiment, frame **310** is composed of a plurality of trays **322** stacked upon one another and attached to or stacked on a base **318**. In such an embodiment, inventory bins **320** may be formed by a plurality of adjustable dividers **324** that may be moved to resize one or more inventory bins **320**. In alternative embodiments, frame **310** may represent a single inventory bin **320** that includes a single tray **322** and no adjustable dividers **324**. Additionally, in particular embodiments, frame **310** may represent a load-bearing surface mounted on mobility element **330**. Inventory items **40** may be stored on such an inventory holder **30** by being placed on frame **310**. In general, frame

310 may include storage internal and/or external storage space divided into any appropriate number of inventory bins 320 in any appropriate manner.

Additionally, in a particular embodiment, frame 310 may include a plurality of device openings 326 that allow mobile drive unit 20 to position docking head 110 adjacent docking surface 350. The size, shape, and placement of device openings 326 may be determined based on the size, the shape, and other characteristics of the particular embodiment of mobile drive unit 20 and/or inventory holder 30 utilized by inventory system 10. For example, in the illustrated embodiment, frame 310 includes four legs 328 that form device openings 326 and allow mobile drive unit 20 to position mobile drive unit 20 under frame 310 and adjacent to docking surface 350. The length of legs 328 may be determined based on a height of mobile drive unit 20.

Docking surface 350 comprises a portion of inventory holder 30 that couples to, abuts, and/or rests upon a portion of docking head 110, when mobile drive unit 20 is docked to inventory holder 30. Additionally, docking surface 350 supports a portion or all of the weight of inventory holder 30 while inventory holder 30 is docked with mobile drive unit 20. The composition, shape, and/or texture of docking surface 350 may be designed to facilitate maneuvering of inventory holder 30 by mobile drive unit 20. For example, as noted above, in particular embodiments, docking surface 350 may comprise a high-friction portion. When mobile drive unit 20 and inventory holder 30 are docked, frictional forces induced between docking head 110 and this high-friction portion may allow mobile drive unit 20 to maneuver inventory holder 30. Additionally, in particular embodiments, docking surface 350 may include appropriate components suitable to receive a portion of docking head 110, couple inventory holder 30 to mobile drive unit 20, and/or facilitate control of inventory holder 30 by mobile drive unit 20.

Holder identifier 360 marks a predetermined portion of inventory holder 30 and mobile drive unit 20 may use holder identifier 360 to align with inventory holder 30 during docking and/or to determine the location of inventory holder 30. More specifically, in particular embodiments, mobile drive unit 20 may be equipped with components, such as holder sensor 150, that can detect holder identifier 360 and determine its location relative to mobile drive unit 20. As a result, mobile drive unit 20 may be able to determine the location of inventory holder 30 as a whole. For example, in particular embodiments, holder identifier 360 may represent a reflective marker that is positioned at a predetermined location on inventory holder 30 and that holder sensor 150 can optically detect using an appropriately-configured camera.

Additionally, in particular embodiments, inventory system 10 includes multiple inventory holders 30 and, in such embodiments, holder identifier 360 may uniquely identify the particular inventory holder 30 to which holder identifier is attached. As one example, in particular embodiments, holder identifier 360 may include a radio-frequency (RF) emitter that transmits an RF signal uniquely identifying inventory holder 30. As mobile drive unit 20 approaches a particular inventory holder 30, mobile drive unit 20 may be configured to detect the RF signal and determine which inventory holder 30 mobile drive unit 20 is approaching based on the detected RF signal. As another example, in particular embodiments, holder identifier 360 represents marker bearing a bar-code, and mobile drive unit 20 may be configured to read this bar-code while passing under inventory holder 30 and determine which inventory holder 30

mobile drive unit 20 is passing beneath based on the contents of the bar-code. Moreover, in such embodiments, the bar-code may represent a two-dimensional bar-code to allow more information to be stored in the bar-code and, thus, a greater number of inventory holders 30 may be utilized within inventory system 10.

FIGS. 4A-4H illustrate operation of particular embodiments of mobile drive unit 20 and inventory holder 30 during docking, movement, and undocking. For purposes of example, FIGS. 4A-4H illustrate particular embodiments of mobile drive unit 20 and inventory holder 30 configured to couple and uncouple while mobile drive unit 20 is positioned beneath inventory holder 30. As noted above, however, alternative embodiments of mobile drive unit 20 and inventory holder 30 may be configured to couple while mobile drive unit 20 is positioned in any appropriate manner relative to inventory holder 30. Additionally, although FIGS. 4A-4H illustrate operation of a particular embodiment of mobile drive unit 20 configured to detect its location and the location of inventory holder 30 using optical sensors, alternative embodiments of mobile drive unit 20 may be configured to determine the relevant locations using other appropriate forms of sensors, as described above.

FIG. 4A illustrates mobile drive unit 20 and inventory holder 30 prior to docking. As noted above with respect to FIG. 1, mobile drive unit 20 may receive a command that identifies a location for a particular inventory holder 30. Mobile drive unit 20 may then move to the location specified in the command. Additionally, mobile drive unit 20 may utilize position sensor 140 to determine the location of mobile drive unit 20 to assist in navigating to the location of inventory holder 30.

In particular, FIG. 4A shows mobile drive unit 20 and inventory holder 30 as mobile drive unit 20 approaches the storage location identified by the received command. In the illustrated embodiment, the reference point is marked by fiducial mark 50a which comprises a surface operable to reflect light and which, as a result, can be detected by particular embodiments of position sensor 140 when mobile drive unit 20 is positioned over or approximately over fiducial mark 50a. As noted above, the illustrated embodiment of mobile drive unit 20 utilizes optical sensors, including a camera and appropriate image- and/or video processing components, to detect fiducial marks 50.

FIG. 4B illustrates mobile drive unit 20 and inventory holder 30 once mobile drive unit 20 reaches fiducial mark 50a. Because, in the illustrated example, fiducial mark 50a marks the location of the reference point to which mobile drive unit 20 is destined, mobile drive unit 20 begins the docking process once mobile drive unit 20 reaches fiducial mark 50a. In the illustrated example, mobile drive unit 20 is configured to dock with inventory holder 30 from a position beneath inventory holder 30 and, as a result, inventory holder 30 is stored so that docking surface 350 is located directly above fiducial mark 50a.

Although in the illustrated example, inventory holder 30, at this point, is assumed to be aligned with or within some tolerance of being aligned with fiducial mark 50a, particular embodiments of mobile drive unit 20 may be configured to additionally determine whether inventory holder 30 is aligned with fiducial mark 50a and, if not, to execute any appropriate additional steps to facilitate docking despite the misalignment of inventory holder 30. For example, in particular embodiments, mobile drive unit 20 may determine whether inventory holder 30 is appropriately aligned with fiducial mark 50a, such as by aligning itself with fiducial mark 50a and determining a difference between the location

of mobile drive unit **20** and the location of inventory holder **30** or an appropriate portion of inventory holder **30**. If the difference between the location of mobile drive unit **20** and the location of inventory holder **30** is greater than some predetermined tolerance, mobile drive unit **20** may then adjust its position based on the detected location of inventory holder **30** to facilitate docking.

FIG. 4C illustrates operation of mobile drive unit **20** in docking with inventory holder **30**. After positioning itself over fiducial mark **50a**, mobile drive unit **20** begins the docking process. In the illustrated example, the docking process includes mobile drive unit **20** raising docking head **110** towards docking surface **350**, as indicated by arrow **510**. Additionally, in the illustrated example, mobile drive unit **20** and inventory holder **30** are configured so that mobile drive unit **20** lifts inventory holder **30** off the ground when mobile drive unit **20** docks with inventory holder **30** and, as a result, mobile drive unit **20** supports the weight of inventory holder **30** while mobile drive unit **20** is docked to inventory holder **30**.

FIG. 4D illustrates operation of mobile drive unit **20** after docking with inventory holder **30**. Mobile drive unit **20** is capable of inducing translational and/or rotational movement in inventory holder **30** while mobile drive unit **20** is docked with inventory holder **30**. For example, in the illustrated embodiment, inventory holder **30** is supported by mobile drive unit **20** while the two components are docked and mobile drive unit **20** is capable of inducing translational and/or rotational movement in inventory holder **30** by moving or rotating itself or some sub-component of itself, such as docking head **110**. As a result, while mobile drive unit **20** and inventory holder **30** are docked mobile drive unit **20** may move inventory holder **30** to a requested destination based on commands received by mobile drive unit **20**, as suggested by arrow **520**.

More specifically, after docking with inventory holder **30**, mobile drive unit **20** may then move inventory holder **30** to the destination identified in the command received by mobile drive unit **20**, propelling and/or rotating inventory holder **30** as appropriate. In particular embodiments, mobile drive unit **20** may monitor and update a calculation of its own location as it moves. For example, in particular embodiments, mobile drive unit **20** detects one or more fiducial marks **50** along the path to the requested destination and updates its location based on the detection of these fiducial marks **50**. As a result, mobile drive unit **20** may be able to maintain an up-to-date approximation of its location while moving.

Once mobile drive unit **20** and inventory holder **30** arrive at the destination, mobile drive unit **20** may additionally rotate inventory holder **30** to present a particular face of inventory holder **30** to a packer or otherwise maneuver inventory holder **30** to allow access to inventory items **40** stored by inventory holder **30**. Mobile drive unit **20** may then undock from inventory holder **30**, as described below, or move inventory holder to another destination. For example, mobile drive unit **20** may move inventory holder **30** to a packing station where a packer can select appropriate inventory items **40** from inventory holder **30**. Mobile drive unit **20** may then return inventory holder **30** to its original location or another location appropriate for undocking, such as a new storage location reserved for inventory holder **30**.

FIG. 4E illustrates mobile drive unit **20** and inventory holder **30** when the two components arrive at an appropriate point for undocking. As noted above, this may represent a final destination specified by the original command, the original storage location for inventory holder **30**, or any

other point within the workspace. At or near the destination, mobile drive unit **20** may detect another fiducial mark **50**, fiducial mark **50b**, associated with the undocking location. Mobile drive unit **20** determines its location based on fiducial mark **50b** and, as a result, determines that it has reached the undocking location.

After determining that it has reached the undocking location, mobile drive unit **20** initiates an appropriate undocking process based on the configuration and characteristics of mobile drive unit **20** and inventory holder **30**. As part of this process, mobile drive unit **20** may align mobile drive unit **20** with one or more fiducial markers **50** or other appropriate reference points on the workspace before undocking. Aligning with these reference points may allow mobile drive unit **20** to align inventory holder **30** to a grid associated with the workspace and, thus, to ensure that mobile drive unit **20** or other components of inventory system **10** can move within the workspace without interfering with inventory holder **30**. After aligning mobile drive unit **20** based on the reference points, mobile drive unit **20** may undock from inventory holder **30**. Mobile drive unit **20** may then execute any appropriate additional steps in undocking from inventory holder **30**. For example, in the illustrated embodiment, mobile drive unit **20** supports inventory holder **30** on docking head **110** while mobile drive unit **20** and inventory holder **30** are docked. As a result, in this embodiment, mobile drive unit **20** undocks from inventory holder **30**, in part, by lowering docking head **110**. As mobile drive unit **20** lowers docking head **110**, the weight of inventory holder **30** will be shifted from mobile drive unit **20** to legs **328**.

Additionally, the location of inventory holder **30** relative to mobile drive unit **20** may shift during transit. As a result, the location of inventory holder **30** may not be properly aligned with fiducial marker **50b** after undocking despite any steps taken by mobile drive unit **20** to align itself to fiducial marker **50b**. Moreover, in particular embodiments, mobile drive units **20** may use the expected location of inventory holders to navigate within the workspace of inventory system **10**. As a result, if inventory holder **30** is left at the requested destination without being properly aligned with fiducial marker **50b**, other mobile drive units **20** may interfere with inventory holder **30**, other mobile drive units **20** may subsequently have difficulty docking with inventory holder **30**, and/or other related problems may arise. Consequently, mobile drive unit **20** may attempt to verify that inventory holder **30** is properly aligned with fiducial mark **50b** and, if not, take appropriate steps to align inventory holder **30** with fiducial mark **50b**.

For example, in particular embodiments, mobile drive unit **20** may, after undocking from inventory holder **30** determine a location of inventory holder **30**. Mobile drive unit **20** may utilize holder sensor **150** to detect the location of inventory holder **30**. Based on the information detected by holder sensor **150**, mobile drive unit **20** may determine the difference between the location of mobile drive unit **20** and the location of inventory holder **30**. If the difference is greater than some predetermined tolerance, mobile drive unit **20** may attempt to move inventory holder **30** to more closely align inventory holder **30** with the current location of mobile drive unit **20** and/or fiducial mark **50b**, as shown in FIGS. 4F-4H.

FIGS. 4F-4H illustrate operation of a particular embodiment of mobile drive unit **20** after determining that the location of inventory holder **30** differs from the location of mobile drive unit **20** and/or fiducial mark **50b** by more than the predetermined tolerance. More specifically, FIG. 4F

illustrates mobile drive unit 20 as mobile drive unit 20 positions itself under inventory holder 30. In particular, after determining that the location of inventory holder 30 differs from the current location of mobile drive unit 20 and/or that of fiducial mark 50b by more than the predetermined tolerance, mobile drive unit 20, in the illustrated embodiment, moves to a new location based on the detected location of inventory holder 30, as shown by arrow 530. In the illustrated embodiment, mobile drive unit 20 repositions itself so that holder sensor 150 is located under holder identifier 360. Mobile drive unit 20 then docks with inventory holder 30 again in a similar manner to that shown in FIG. 4C.

FIG. 4G illustrates the operation of a particular embodiment of mobile drive unit 20 after docking with inventory holder 30 a second time to correct the location of inventory holder 30. After docking with inventory holder 30 again, mobile drive unit 20 moves back towards the requested destination, as suggested by arrow 540. Mobile drive unit 20 may continue moving towards the requested destination until mobile drive unit 20 detects fiducial mark 50b again.

FIG. 4H illustrates the operation of a particular embodiment of mobile drive unit 20 after reaching the requested destination a second time. After aligning with fiducial mark 50b again, mobile drive unit 20 undocks from inventory holder 30. In the illustrated embodiment, mobile drive unit 20 undocks from inventory holder 30 by lowering docking head 110 as suggested by arrow 550. Because, in particular embodiments, the movement to correctly align inventory holder 30 with the requested destination will often be significantly smaller than the movement from the original location to the requested destination, the chances of any slippage, jostling, or other error-inducing incidents will be much smaller. Consequently, this correction technique may substantially improve the precision with which inventory holder 30 can be stored.

Mobile drive unit 20 may then move away from inventory holder 30 and begin responding to other commands received by mobile drive unit 20. Alternatively, mobile drive unit 20 may repeat the determination of the location of inventory holder 30 and again attempt to align inventory holder 30 to fiducial mark 50b. Moreover, mobile drive unit 20 may perform these steps until completing a predetermined number of iterations or indefinitely until inventory holder 30 is finally aligned with fiducial mark 50b. Repeating this process may improve the precision of the inventory holder's storage beyond the improvement produced by the initial correction.

In alternative embodiments, mobile drive unit 20 may use information from sensor 140 and sensor 150 to calculate the relative offset of inventory holder 30 from desired location 50b and then make corrective moves prior to undocking that results in inventory holder 30 being positioned within tolerance to fiducial 50b. This process reduces the amount of time required to accurately place the inventory holder 30 on the grid. Additionally, mobile drive unit 20 may perform this difference calculation at any point along a path to or from storage destinations and make a determination that it should undock and redock to improve the location of the inventory holder 30 relative to the drive unit 20. An example of this operation is discussed below with respect to FIG. 7.

Thus, in particular embodiments of inventory system 10, mobile drive unit 20 may be capable of using certain techniques to correct the location of inventory holder 30 after transporting inventory holder 30 between points within the workspace of inventory system 10. This may reduce the occurrence of operational errors in inventory system 10.

Additionally, in particular embodiments, implementation of such techniques may also allow for greater automation of the operation of inventory system 10, permit the use of a smaller workspace, and/or prevent improperly positioned inventory holders 30 from interfering with the normal operation of the inventory system 10. As a result, particular embodiments of mobile drive unit 20 may provide multiple benefits. Nonetheless, although particular embodiments of mobile drive unit 20 may provide such benefits, alternative embodiments may provide some, none, or all of these benefits.

Additionally, although FIGS. 4A-4H focus, for the sake of illustration, on an embodiment of mobile drive unit 20 that detects and correct misalignments of inventory holder 30 immediately following undocking, in alternative embodiments, mobile drive unit 20 may be configured to detect a misalignment at other appropriate times after mobile drive unit 20 has moved inventory holder 30. Moreover, the techniques utilized by mobile drive unit 20 to detect and correct the misalignment may vary depending on when mobile drive unit 20 detects and/or corrects the misalignment. As discussed below, FIG. 5 is a flowchart detailing a technique utilized by particular embodiments of mobile drive unit 20 to detect and correct misalignments of inventory holder 30 immediately after undocking, similar to the embodiment and techniques illustrated in FIGS. 4A-4H. Furthermore, FIG. 6 is a flowchart detailing a technique utilized by particular embodiments of mobile drive unit 20 to detect and correct misalignments of inventory holder 30 before subsequent dockings with that inventory holder 30. In general, however, mobile drive unit 20 may be configured to detect and/or correct the misalignment of inventory holder 30 at any appropriate time using any suitable techniques.

FIG. 5 is a flowchart illustrating operation of a particular embodiment of mobile drive unit 20 during the docking and undocking process illustrated by FIGS. 4A-4H. Some of the steps illustrated in FIG. 5 may be combined, modified, or deleted where appropriate, and additional steps may also be added to the flowchart. Additionally, steps may be performed in any suitable order without departing from the scope of the invention.

Operation begins at step 600 with mobile drive unit 20 receiving a command identifying an inventory holder 30 to be moved or a location for an inventory holder 30 to be moved. In response to receiving the command, mobile drive unit 20 moves to or near the starting location for the identified inventory holder 30 at step 602. In particular embodiments, mobile drive unit 20 may position mobile drive unit 20 under the identified inventory holder 30, at step 604, or perform any other adjustments to align mobile drive unit 20 with inventory holder 30, prepare mobile drive unit 20 or inventory holder 30 for docking, and/or otherwise facilitate docking and transport.

Mobile drive unit 20 may then initiate docking at step 606. In particular embodiments, mobile drive unit 20 initiates docking by raising docking head 110. When docking head 110 contacts docking surface 350 of inventory holder 30, mobile drive unit 20 begins lifting inventory holder 30 off the ground. As a result, in such embodiments, mobile drive unit 20 supports inventory holder 30 once mobile drive unit 20 is docked with inventory holder 30.

At step 608, mobile drive unit 20 moves inventory holder 30 towards a destination requested by the received command. As noted above, while moving, mobile drive unit 20 may continually monitor and/or periodically make an updated determination of the location of mobile drive unit 20 and/or the relative positions of mobile drive unit 20 and inventory holder 30. In particular embodiments, mobile

15

drive unit 20 may monitor or determine the location of mobile drive unit 20 by detecting fixed objects, such as fiducial markers 50, as mobile drive unit 20 moves.

At step 610, mobile drive unit 20 determines that mobile drive unit 20 has reached the requested destination. In particular embodiments, mobile drive unit 20 may determine that mobile drive unit 20 has reached the requested determination by detecting a fixed object, such as a fiducial marker 50 associated with the requested destination. Upon reaching the requested destination, mobile drive unit 20 undocks from inventory holder 30 at step 612. In particular embodiments, mobile drive unit 20 may undock by lowering a docking head 110 that is supporting inventory holder 30.

After undocking, mobile drive unit 20, mobile drive unit 20 may determine the location of inventory holder 30 at step 614. Alternatively, in certain embodiments, mobile drive unit 20 may determine the location of inventory holder 30 prior to undocking. In general, however, mobile drive unit 20 may include a holder sensor 150 that is capable of detecting some portion or feature of inventory holders 30, such as a holder identifier 360, that holder sensor 150 can use to determine the location of the relevant inventory holder 30 relative to mobile drive unit 20. Mobile drive unit 20 may then calculate, at step 616, a difference between the location of inventory holder 30 and the requested destination. At step 618, mobile drive unit 20 may determine whether the difference is greater than a predetermined tolerance. If the difference is not greater than the predetermined tolerance, mobile drive unit 20 may then move away from inventory holder 30, at step 620, and proceed with responding to other commands. The operation of mobile drive unit 20, with respect to moving this inventory holder 30, may then end, as shown in FIG. 5.

If instead, the difference is greater than the predetermined tolerance, mobile drive unit 20 may move mobile drive unit 20 to another point based on the determined location of inventory holder 30 and/or the difference between the determined location of inventory holder 30 and the requested destination. For example, in particular embodiments, such as the one illustrated in FIGS. 4A-4H, mobile drive unit 20 may move to the detected location of inventory holder 30 at step 622. Mobile drive unit 20 then docks with inventory holder 30 again at step 624.

After docking with inventory holder 30 again, mobile drive unit 20 moves inventory holder 30 towards the requested destination at step 626. When mobile drive unit 20 reaches the requested destination, mobile drive unit 20 undocks from inventory holder 30 again at step 628. Mobile drive unit 20 may then move away from inventory holder 30, at step 630, and proceed with responding to other commands. The operation of mobile drive unit 20, with respect to moving this inventory holder 30, may then end, as shown in FIG. 5. Alternatively, in particular embodiments, mobile drive unit 20 may determine the location of inventory holder 30 again and repeat any of the above steps again as appropriate based on the configuration of mobile drive unit 20.

Additionally, in alternative embodiments, mobile drive unit 20 may detect and correct misalignments in inventory holder 30 before undocking from inventory holder 30 the first time. This may allow mobile drive unit 20 to reduce the time and/or power expended in correcting misalignments. An example of such a process is illustrated below with respect to FIG. 7.

FIG. 6 is a flowchart illustrating operation of an alternative embodiment of mobile drive unit 20 in detecting and correcting a misalignment of inventory holder 30 subsequent to inventory holder 30 being moved within the workspace of

16

inventory system 10. Any of the steps illustrated in FIG. 6 may be combined, modified, or deleted where appropriate, and additional steps may also be added to the flowchart. Additionally, steps may be performed in any suitable order without departing from the scope of the invention.

In the example, described by the flowchart in FIG. 6, mobile drive unit 20 begins operation undocked from any inventory holder 30. Operation begins at step 700 with mobile drive unit 20 receiving a command identifying an inventory holder 30 to be moved or a location for an inventory holder 30 to be moved and a desired destination for that inventory holder 30. In response to receiving the command, mobile drive unit 20 moves to or near the starting location for the identified inventory holder 30 at step 702. In particular embodiments, mobile drive unit 20 may position mobile drive unit 20 under the identified inventory holder 30, at step 704, or perform any other adjustments to align mobile drive unit 20 with inventory holder 30, prepare mobile drive unit 20 or inventory holder 30 for docking, and/or otherwise facilitate docking and transport.

Additionally, in the described embodiment, mobile drive unit 20 may determine the location of inventory holder 30 at step 706. At step 708, mobile drive unit 20 may determine a difference between the location of inventory holder 30 and the designated location for that inventory holder 30. For example, the command received by mobile drive unit 20 may identify a location at which this same mobile drive unit 20 or another mobile drive unit 20 previously stored the relevant inventory holder 30. Mobile drive unit 20 may move to the designated location, determine the actual location of inventory holder 30 once at or near the designated location, and calculate a difference between the actual location and the designated location.

If the difference between the actual location of inventory holder 30 and the designated location of inventory holder 30 is greater than some predetermined tolerance, in particular embodiments, mobile drive unit 20 may take appropriate remedial action to correct the misalignment. For example, in the described embodiment, mobile drive unit 20 calculates a correction value based on the difference between the designated location and the actual location at step 710.

Additionally, in the described embodiment, mobile drive unit 20 determines an adjusted destination using the correction value at step 712. For example, if mobile drive unit 20 determines upon arriving at the designated location that the relevant inventory holder 30 is a quarter inch east of the designated location for that inventory holder 30, mobile drive unit 20 may determine an adjusted destination that is a quarter inch west of the destination location specified by the command.

At step 714, mobile drive unit 20 may dock with inventory holder 30. Mobile drive unit 20 may then move mobile drive unit 20 and inventory holder 30 to the adjusted destination at step 716. At step 718, mobile drive unit 20 may undock from inventory holder 30 at the adjusted destination. In particular embodiments, mobile drive unit 20 may take additional steps to detect and/or correct any remaining or subsequently occurring misalignment of inventory holder 30 after arriving at the adjusted destination and/or after undocking to further reduce the potential for misalignments. For example, in particular embodiments, mobile drive unit 20 may, after undocking, attempt to detect and correct any misalignments using techniques similar to those described above in FIG. 5. Mobile drive unit 20 may then move away from inventory holder 30, at step 740, and proceed with responding to other commands. The operation

of mobile drive unit 20, with respect to moving this inventory holder 30, may then end, as shown in FIG. 6.

As noted above, the steps illustrated in FIG. 6 may be performed in any appropriate order. For example, instead of determining the location of inventory holder 30 prior to docking, mobile drive unit 20 may alternatively determine the location of inventory holder 30 relative to mobile drive unit 20 after docking with inventory holder 30 and while in transit to the destination location. Mobile drive unit 20 may then use this relative location of inventory holder 30 to calculate the adjustment factor and to determine the adjusted destination. An example of such a process is illustrated below with respect to FIG. 8.

FIG. 7 is a flowchart illustrating another example technique that may be utilized by particular embodiments of mobile drive units 20 to detect and correct misalignments when transporting inventory holders 30. In particular, FIG. 7 illustrates a technique in which, after moving an inventory holder 30 to a requested destination, mobile drive unit 20 may detect a misalignment in the relevant inventory holder 30 prior to undocking from that inventory holder 30. Some of the steps illustrated in FIG. 7 may be combined, modified, or deleted where appropriate, and additional steps may also be added to the flowchart. Furthermore, steps may be performed in any suitable order without departing from the scope of the invention.

In this embodiment, operation begins at step 800 with mobile drive unit 20 receiving a command identifying an inventory holder 30 to be moved or a location for an inventory holder 30 to be moved. In response to receiving the command, mobile drive unit 20 moves to or near the starting location for the identified inventory holder 30 at step 802. In particular embodiments, mobile drive unit 20 may position mobile drive unit 20 under the identified inventory holder 30, at step 804, or perform any other adjustments to align mobile drive unit 20 with inventory holder 30, prepare mobile drive unit 20 or inventory holder 30 for docking, and/or otherwise facilitate docking and transport.

Mobile drive unit 20 may then initiate docking at step 806. In particular embodiments, mobile drive unit 20 initiates docking by raising docking head 110. When docking head 110 contacts docking surface 350 of inventory holder 30, mobile drive unit 20 begins lifting inventory holder 30 off the ground. As a result, in such embodiments, mobile drive unit 20 supports inventory holder 30 once mobile drive unit 20 is docked with inventory holder 30.

At step 808, mobile drive unit 20 moves inventory holder 30 towards a destination requested by the received command. As noted above, while moving, mobile drive unit 20 may continually monitor and/or periodically make an updated determination of the location of mobile drive unit 20 and/or the relative position of mobile drive unit 20 and inventory holder 30. In particular embodiments, mobile drive unit 20 may monitor or determine the location of mobile drive unit 20 by detecting fixed objects, such as fiducial markers 50, as mobile drive unit 20 moves. At step 810, mobile drive unit 20 determines that mobile drive unit 20 has reached the requested destination. In particular embodiments, mobile drive unit 20 may determine that mobile drive unit 20 has reached the requested destination by detecting a fixed object, such as a fiducial marker 50 associated with the requested destination.

Upon reaching the requested destination, mobile drive unit 20 may determine the location of inventory holder 30 at step 812. As noted above, mobile drive unit 20 may include a holder sensor 150 that is capable of detecting some portion or feature of inventory holders 30, such as a holder identifier

360, that holder sensor 150 can use to determine the location of the relevant inventory holder 30 relative to mobile drive unit 20. Mobile drive unit 20 may then calculate, at step 814, a difference between the location of inventory holder 30 and the requested destination. At step 816, mobile drive unit 20 may determine whether the difference is greater than a predetermined tolerance.

If the difference is not greater than a predetermined tolerance, mobile drive unit 20 may undock from inventory holder 30 at step 818. In particular embodiments, mobile drive unit 20 may undock by lowering a docking head 110 that is supporting inventory holder 30. Mobile drive unit 20 may then move away from inventory holder 30, at step 820, and proceed with responding to other commands. The operation of mobile drive unit 20, with respect to moving this inventory holder 30, may then end, as shown in FIG. 7.

If, instead, the difference between the actual location of inventory holder 30 and the requested destination is greater than the predetermined tolerance, in particular embodiments, mobile drive unit 20 may take appropriate remedial action to correct the misalignment. For example, in the described embodiment, mobile drive unit 20 calculates a correction value based on the difference between the requested destination and the actual location of inventory holder 30 at step 822. In particular embodiments, the correction value may represent a distance and/or direction in which to adjust the location of inventory holder 30 to correct for the detected misalignment.

Additionally, in the described embodiment, mobile drive unit 20 determines an adjusted destination using the correction value at step 824. For example, if mobile drive unit 20 determines upon arriving at the requested destination that the relevant inventory holder 30 has shifted during transport and is now a quarter inch to the east of its anticipated location while docked with mobile drive unit 20, mobile drive unit 20 may determine an adjusted destination that is a quarter inch west of the requested destination specified by the command. Mobile drive unit 20 may then move mobile drive unit 20 and inventory holder 30 to the adjusted destination at step 826.

At step 828, mobile drive unit 20 may then undock from inventory holder 30 at the adjusted destination. In particular embodiments, mobile drive unit 20 may take additional steps to detect and/or correct any remaining or subsequently occurring misalignment of inventory holder 30 after arriving at the adjusted destination and/or after undocking to further reduce the potential for misalignments. For example, in particular embodiments, mobile drive unit 20 may, after undocking, attempt to detect and correct any misalignments using techniques similar to those described above in FIG. 5. Mobile drive unit 20 may then move away from inventory holder 30, at step 830, and proceed with responding to other commands. The operation of mobile drive unit 20, with respect to moving this inventory holder 30, may then end, as shown in FIG. 6.

By determining whether inventory holder 30 is misaligned before undocking, particular embodiments of mobile drive unit 20 may be able to limit the time and power expended in correcting such misalignments. In particular embodiments, this may reduce the time required to respond to orders and/or limit the frequency with which mobile drive units 20 must recharge its power supply. As a result, embodiments of mobile drive unit 20 that operate as described by FIG. 7 may provide a number of operational benefits.

FIG. 8 illustrates another example technique that may be utilized by certain embodiments of mobile drive unit 20 in detecting and correcting misalignments of inventory holder

19

30. In particular, FIG. 8 illustrates a technique in which mobile drive unit 20 determines, while in transit to a requested destination, that inventory holder 30 is misaligned and corrects for this misalignment before arriving at the requested destination. Some of the steps illustrated in FIG. 8 may be combined, modified, or deleted where appropriate, and additional steps may also be added to the flowchart. Additionally, steps may be performed in any suitable order without departing from the scope of the invention.

In this embodiment, operation begins at step 900 with mobile drive unit 20 receiving a command identifying an inventory holder 30 to be moved or a location for an inventory holder 30 to be moved. In response to receiving the command, mobile drive unit 20 moves to or near the starting location for the identified inventory holder 30 at step 902. In particular embodiments, mobile drive unit 20 may position mobile drive unit 20 under the identified inventory holder 30, at step 904, or perform any other adjustments to align mobile drive unit 20 with inventory holder 30, prepare mobile drive unit 20 or inventory holder 30 for docking, and/or otherwise facilitate docking and transport.

Mobile drive unit 20 may then initiate docking at step 906. In particular embodiments, mobile drive unit 20 initiates docking by raising docking head 110. When docking head 110 contacts docking surface 350 of inventory holder 30, mobile drive unit 20 begins lifting inventory holder 30 off the ground. As a result, in such embodiments, mobile drive unit 20 supports inventory holder 30 once mobile drive unit 20 is docked with inventory holder 30. At step 908, mobile drive unit 20 moves inventory holder 30 towards a destination requested by the received command.

At some point while moving toward the requested destination, mobile drive unit 20 may determine the location of inventory holder 30 relative to mobile drive unit 20, as shown at step 910. For example, in particular embodiments, mobile drive unit 20 may be configured to periodically check the location of inventory holder 30 relative to mobile drive unit 20 while moving inventory holder 30 to the requested destination. Mobile drive unit 20 then calculates, at step 912, a difference between the location of inventory holder 30 and its anticipated location while docked with mobile drive unit 20. In particular embodiments, mobile drive unit 20 may be programmed with information specifying the anticipated location of a particular portion of inventory holder 30 (such as holder identifier 360) relative to mobile drive unit 20 when inventory holder 30 is docked and properly aligned with mobile drive unit 20. In such embodiments, mobile drive unit 20 may calculate the difference between the location of inventory holder 30 and its anticipated location based on the difference between the location of the relevant portion and the anticipated location of that portion of inventory holder 30.

At step 914, mobile drive unit 20 then determines whether the difference between the actual location of inventory holder 30 and the anticipated location of inventory holder 30 is greater than a predetermined tolerance. If the difference is not greater than the predetermined tolerance, operation of mobile drive unit 20 continues at step 924. If, instead, the difference is greater than the predetermined tolerance, mobile drive unit 20 may determine a correction value based on this difference at step 916. As noted above, mobile drive unit 20 may, in particular embodiments, be programmed with information specifying the anticipated location of a particular portion of inventory holder 30 (such as holder identifier 360) relative to mobile drive unit 20. Mobile drive unit 20 may determine, while moving, the location of this portion of inventory holder 30 and, if the location of the

20

relevant portion differs from its anticipated location by more than the predetermined tolerance, determine an appropriate correction value based on the magnitude and/or direction of the misalignment. For example, if mobile drive unit 20 determines that the relevant portion of inventory holder 30 is a quarter inch to the east of the anticipated location for this portion of inventory holder 30, mobile drive unit 20 may determine a correction value that is a quarter inch to the west.

Mobile drive unit 20 then undocks from inventory holder 30 at step 918. At step 920, mobile drive unit 20 moves a distance and/or direction determined based on the correction value. Returning to the quarter-inch misalignment example, mobile drive unit 20, in accordance with the correction value calculated for this misalignment, moves a quarter inch to the west to correct the misalignment. Then, after completing any appropriate movements based on the correction value, mobile drive unit 20 re-docks with inventory holder at step 922.

After correcting any existing misalignment or determining that any misalignment is less than the predetermined tolerance, mobile drive unit 20 may continue moving toward the requested destination at step 924. At step 926, mobile drive unit 20 may then determine that mobile drive unit 20 has reached the requested destination. Mobile drive unit 20 then undocks from inventory holder 30 at step 928. After undocking, mobile drive unit 20 may then move away from inventory holder 30 and respond to other commands at step 930. Operation of mobile drive unit 20 with respect to moving this particular inventory holder 30 may then end as shown in FIG. 8.

Although the present invention has been described with several embodiments, a myriad of changes, variations, alterations, transformations, and modifications may be suggested to one skilled in the art, and it is intended that the present invention encompass such changes, variations, alterations, transformations, and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A system for navigation, comprising:

a plurality of fiducial marks arranged in a two-dimensional grid in a workspace;

a mobile drive unit, comprising:

a position sensor operable to sense information associated with a first fiducial mark in the two-dimensional grid;

a processing unit operable to process the information to produce information that identifies a location associated with the first fiducial mark within the two-dimensional grid; and

a wireless transmission module operable to wirelessly transmit the information identifying the location associated with the first fiducial mark to a remote control module, wherein the remote control module utilizes the information identifying the location associated with the first fiducial mark to facilitate navigation within the workspace.

2. The system of claim 1, wherein the remote control module is further operable to:

wirelessly receive the identifying information;

determine that the mobile drive unit is located at the first fiducial mark based at least in part upon the information identifying the first fiducial mark; and

calculate a path to a second fiducial mark in the two-dimensional grid based at least in part upon the information identifying the first fiducial mark.

21

3. The system of claim 2, wherein the first and second fiducial marks comprise unique identifiers that are affixed to a floor of the workspace.

4. The system of claim 1, wherein the transmitting of the information identifying the location associated with the first fiducial mark indicates to the remote control module that the mobile drive unit is proximate to the first fiducial mark.

5. The system of claim 1, wherein the mobile drive unit further comprises a docking mechanism operable to:

raise a docking head of the mobile drive unit towards a surface of an inventory holder; and

engage a docking head with the surface of the inventory holder.

6. The system of claim 1, wherein the position sensor comprises a camera operable to optically detect the first fiducial mark in response to sensing that a fiducial mark is in a view of the camera.

7. The system of claim 1, wherein the remote control module is further operable to:

determine locations of one or more other mobile drive units in the workspace based on receiving information associated with fiducial marks from the other mobile drive units; and

calculate a path from one fiducial mark to another fiducial mark that avoids collisions with the one or more other mobile drive units based at least in part upon the information.

8. A mobile drive unit operable to:

detect a first fiducial mark within a two-dimensional grid of fiducial marks in a workspace, wherein the second fiducial mark identifies a fixed location of the mobile drive unit within the two-dimensional grid of fiducial marks in the workspace;

determine the location of the mobile drive unit within the two-dimensional grid of fiducial marks in the workspace based on the identified particular location; and

navigate from the first fiducial mark to a second fiducial mark by providing the location of the mobile drive unit to a remote control module.

9. The mobile drive unit of claim 8, wherein the mobile drive unit is further operable to:

transmit information associated with the first fiducial mark to the remote control module; and

receive, from the remote control module, a path from the first fiducial mark to the second fiducial mark in the two-dimensional grid of fiducial marks.

10. The mobile drive unit of claim 9, wherein the path is calculated to avoid collisions with objects in the workspace.

11. The mobile drive unit of claim 8, wherein detect the first fiducial mark comprises sensing the first fiducial mark using a position sensor.

22

12. The mobile drive unit of claim 8, wherein:

the second fiducial mark in the two-dimensional grid of fiducial marks is associated with an inventory holder; and

the mobile drive unit is further operable to:

determine that the inventory holder is located at the second fiducial mark; and

dock with the inventory holder at the second fiducial mark.

13. The mobile drive unit of claim 8, wherein the particular location comprises a position of the mobile drive unit in relation to one or more fixed objects in the workspace.

14. A method for transporting inventory items, comprising:

sensing, by a mobile drive unit, information associated with a first fiducial mark within a two-dimensional grid of fiducial marks;

processing, by the mobile drive unit, the information to produce an identifier associated with a location of the first fiducial mark within the two-dimensional grid of fiducial marks;

transmitting, by the mobile drive unit, the information identifying the identifier associated with the location of the first fiducial mark to a remote control module; and

receiving, by the mobile drive unit, navigation information from the remote control module instructing the mobile drive unit to move to a second fiducial mark, the navigation information calculated by the remote control module based at least in part upon the information identifying the identifier associated with the location of the first fiducial mark.

15. The method of claim 14, wherein the information identifying the identifier associated with the location of the first fiducial mark is used by the remote control module to calculate a location of the mobile drive unit based on a known fixed position of the first fiducial mark in a workspace.

16. The method of claim 14, further comprising moving the mobile drive unit to the second fiducial mark based at least upon the navigation information.

17. The method of claim 14, wherein the first and second fiducial marks are affixed to a floor of a workspace.

18. The method of claim 14, further comprising:

docking the mobile drive unit with an inventory holder at the second fiducial mark; and

moving the mobile drive unit away from the second fiducial mark.

19. The method of claim 18, further comprising undocking the mobile drive unit from the inventory holder at a third fiducial mark.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,436,184 B2
APPLICATION NO. : 14/252570
DATED : September 6, 2016
INVENTOR(S) : Raffaello D'Andrea et al.

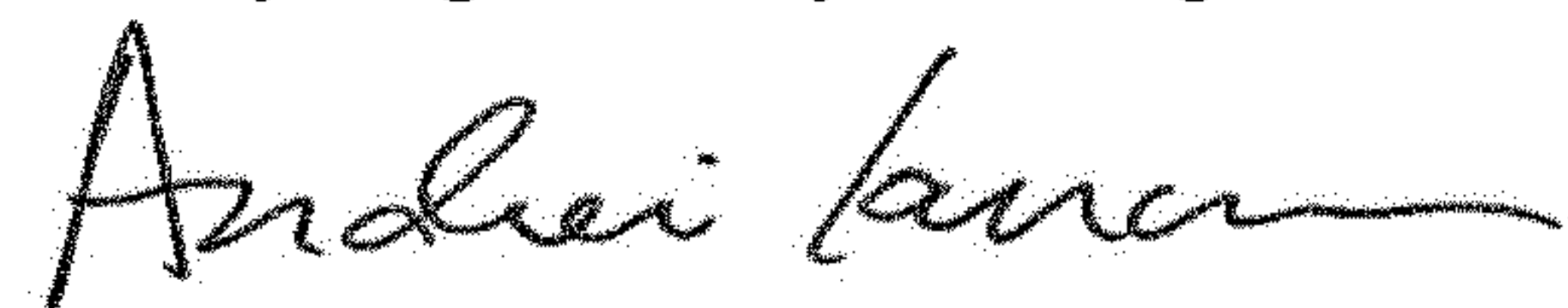
Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (60), Related U.S. Application Data: Before "application No. 13/553,024,"
delete "Continuation-in-part of" and insert -- Continuation of --.

Signed and Sealed this
Twenty-eighth Day of August, 2018



Andrei Iancu
Director of the United States Patent and Trademark Office